Earthquakes in western Washington

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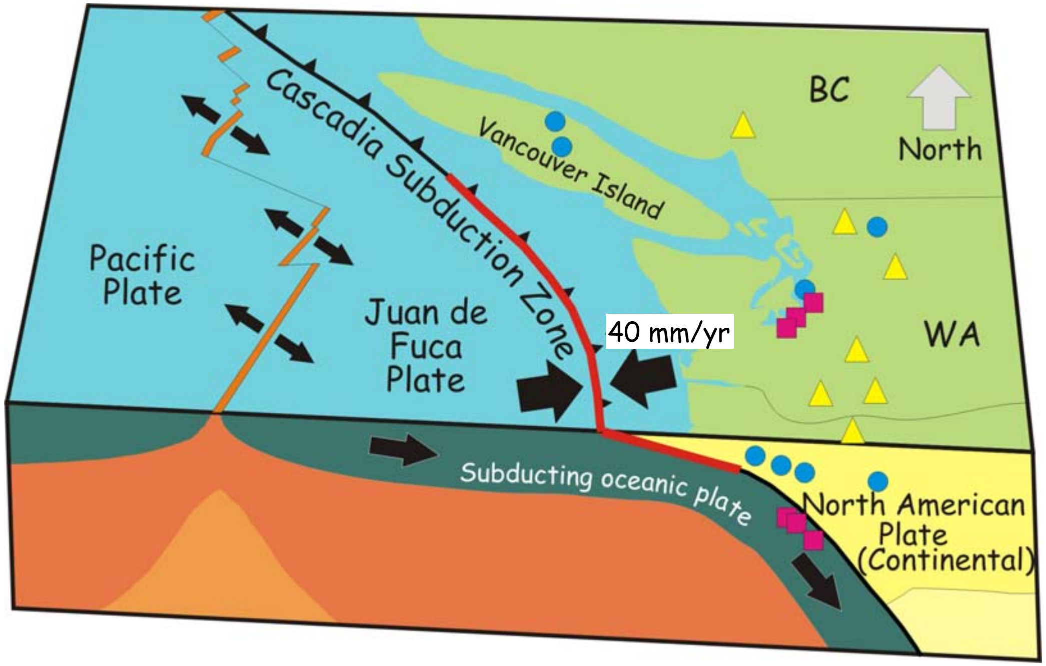
Seattle, Washington

U.S. Department of the Interior
U.S. Geological Survey

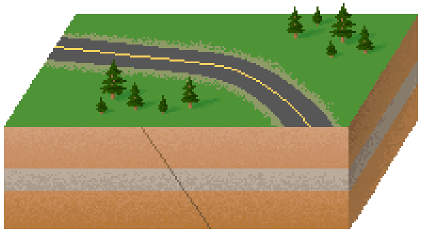


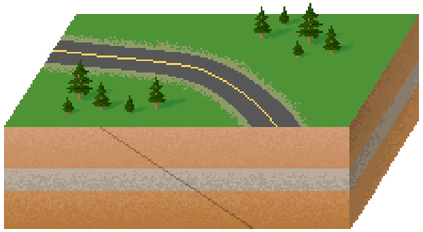
Earthquake Sources

- ■ Deep earthquakes (Intraslab)
- ● Shallow earthquakes (in Nam)
- ╲ Subduction zone earthquakes

- ▲ Cascade volcano

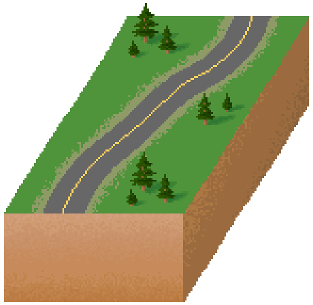
Three Fault Types



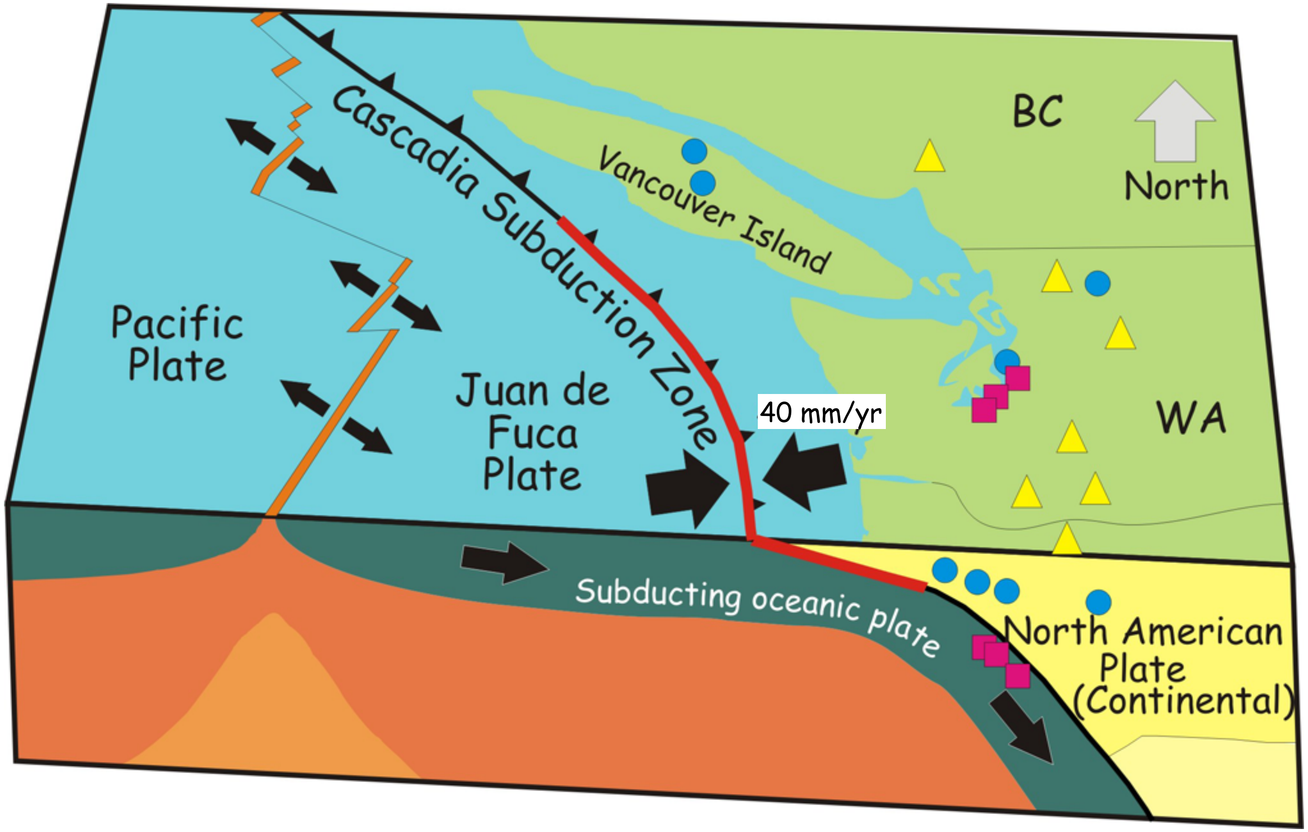


1. Normal fault

2. Reverse fault
(or thrust fault)



3. Transform fault



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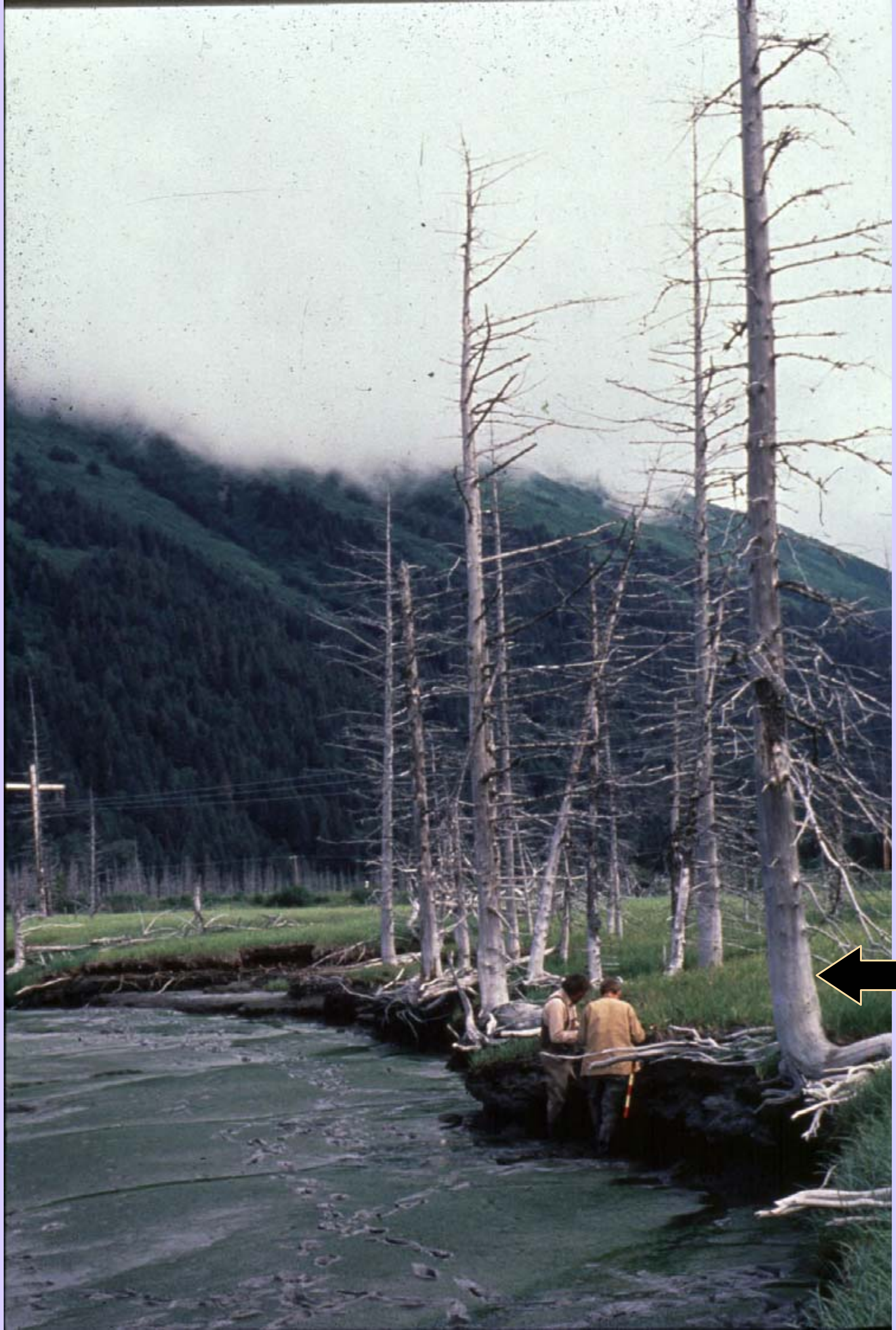
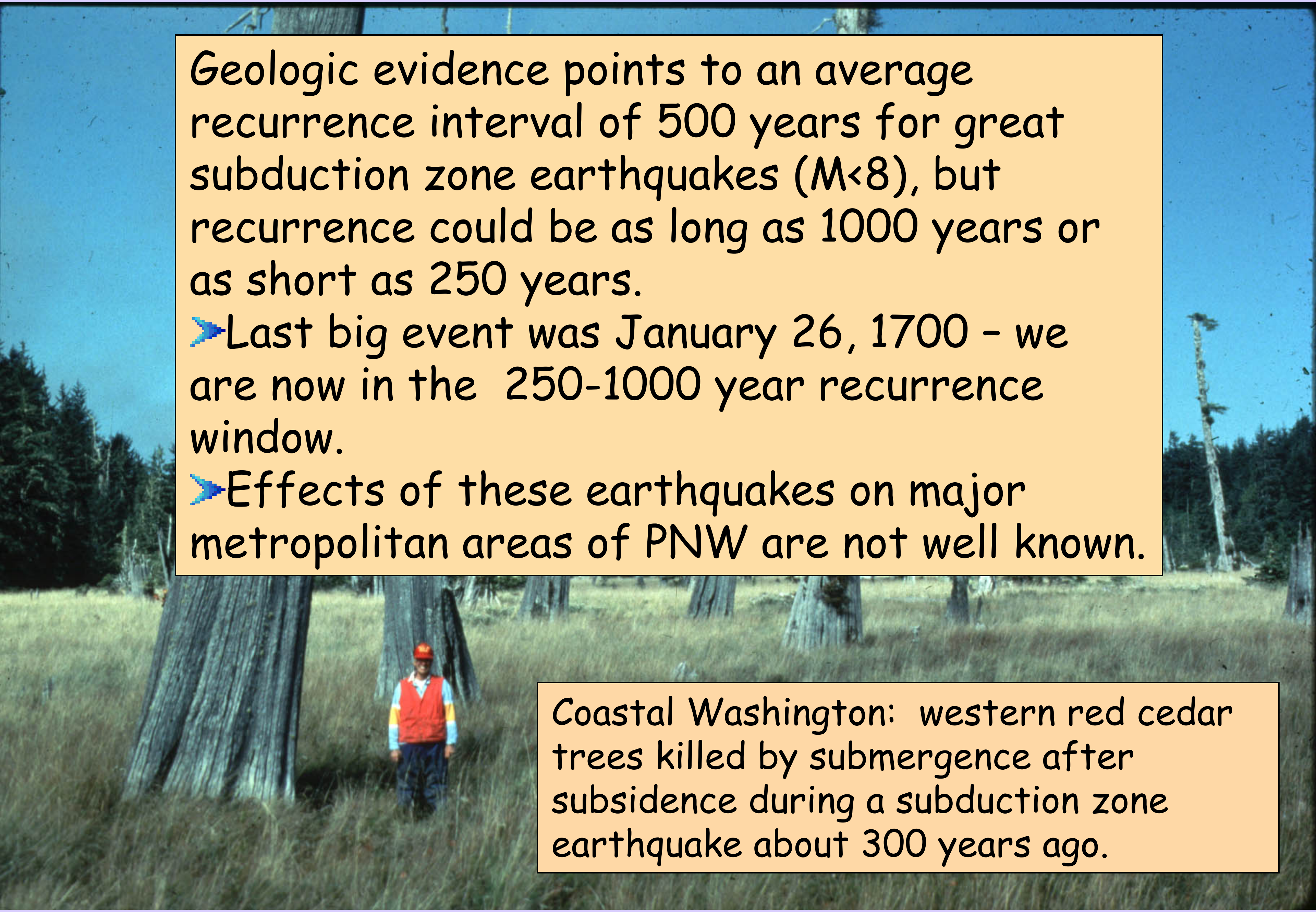


Lesson from 1964 Alaska Earthquake:

Areas of the coastline subside during great subduction zone earthquakes (M_w > 8.0).

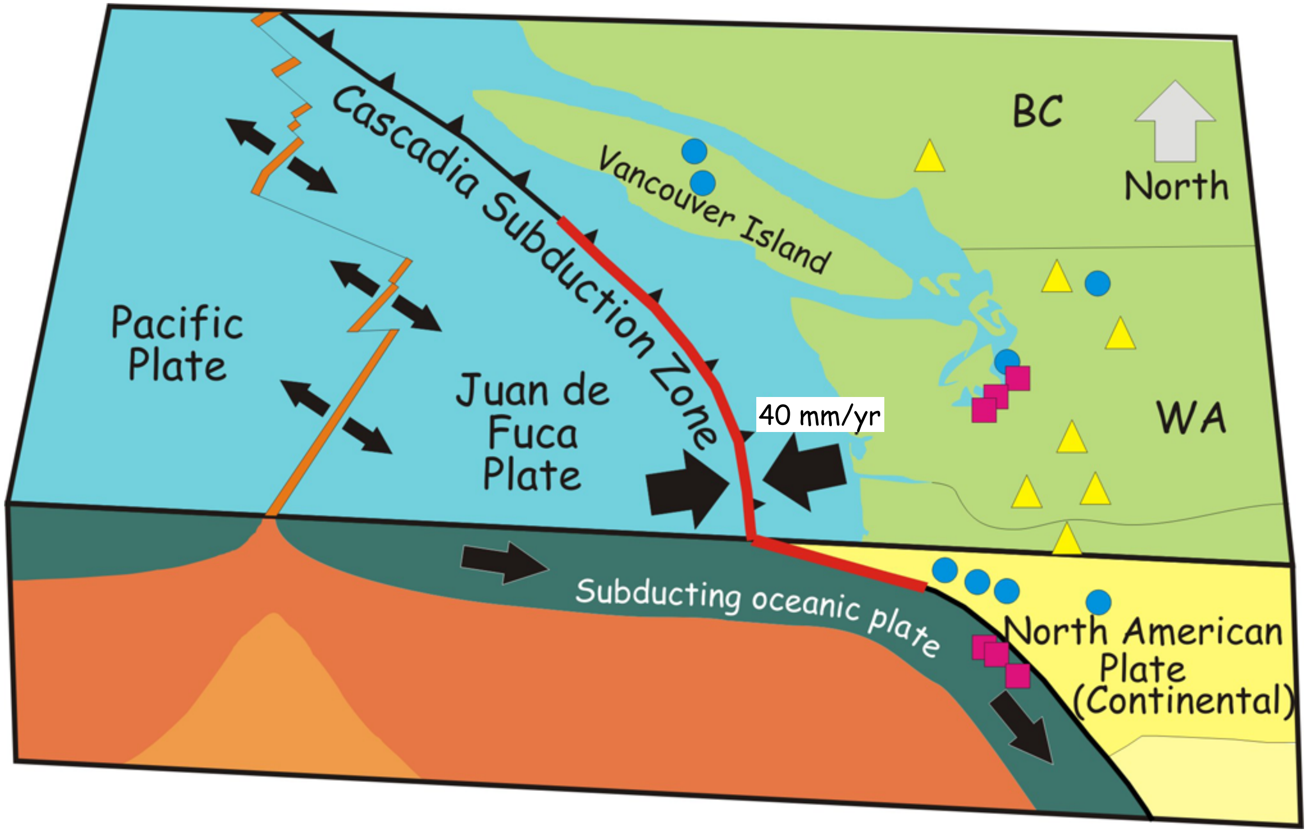
Spruce trees killed when saltwater flooded forest after subsidence lowered them into the intertidal zone



Geologic evidence points to an average recurrence interval of 500 years for great subduction zone earthquakes (M<8), but recurrence could be as long as 1000 years or as short as 250 years.

- Last big event was January 26, 1700 – we are now in the 250-1000 year recurrence window.
- Effects of these earthquakes on major metropolitan areas of PNW are not well known.

Coastal Washington: western red cedar trees killed by submergence after subsidence during a subduction zone earthquake about 300 years ago.



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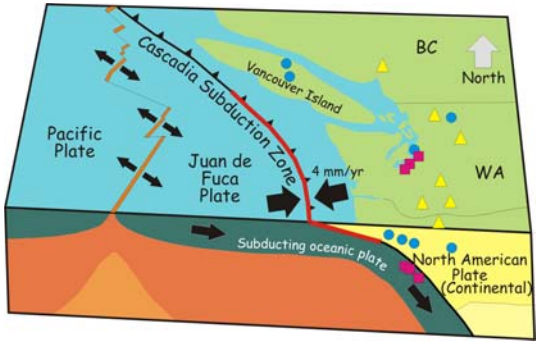
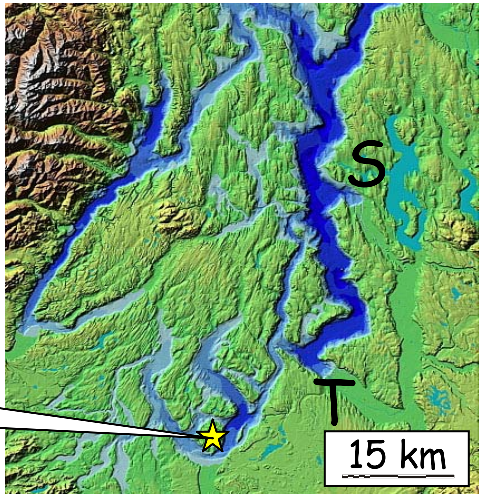
Nisqually Earthquake

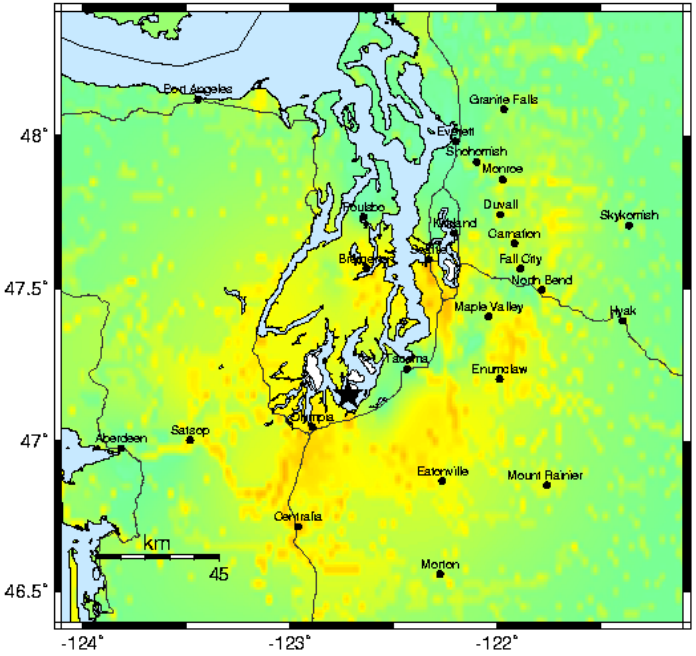
- Mw = 6.8
- Depth = 52.4 km (32.5 miles)
- Intraslab normal fault event



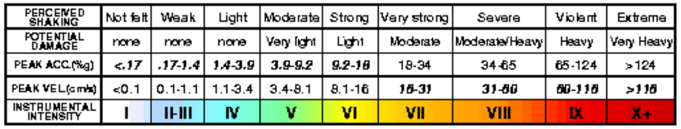


2/28/01
Mw = 6.8

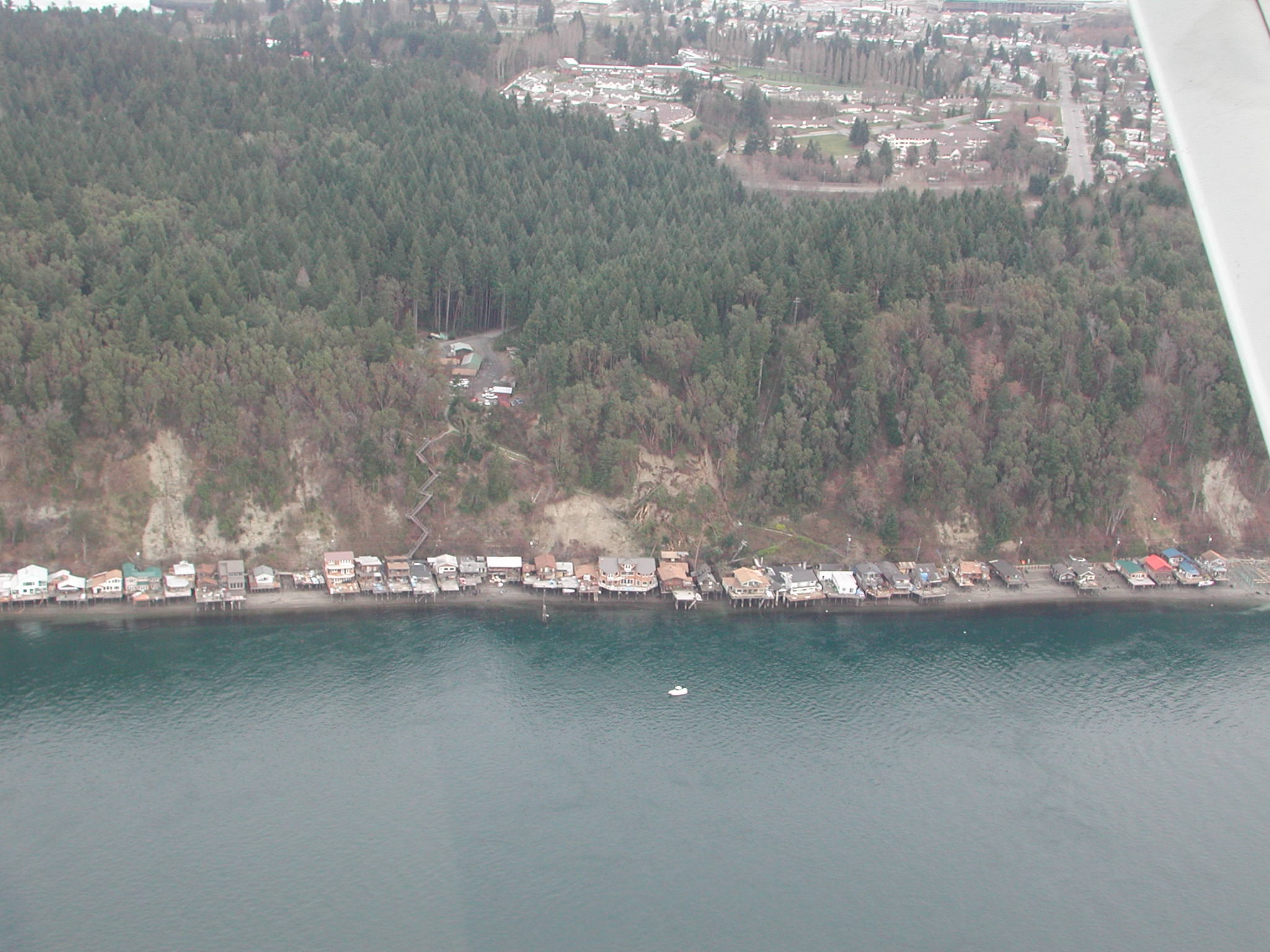
PNSN Rapid Instrumental Intensity Map Epicenter: 17.6 km NE of Olympia, WA
Wed Feb 28, 2001 10:54:00 AM PST M 6.8 N47.15 W122.72 ID:0102281854

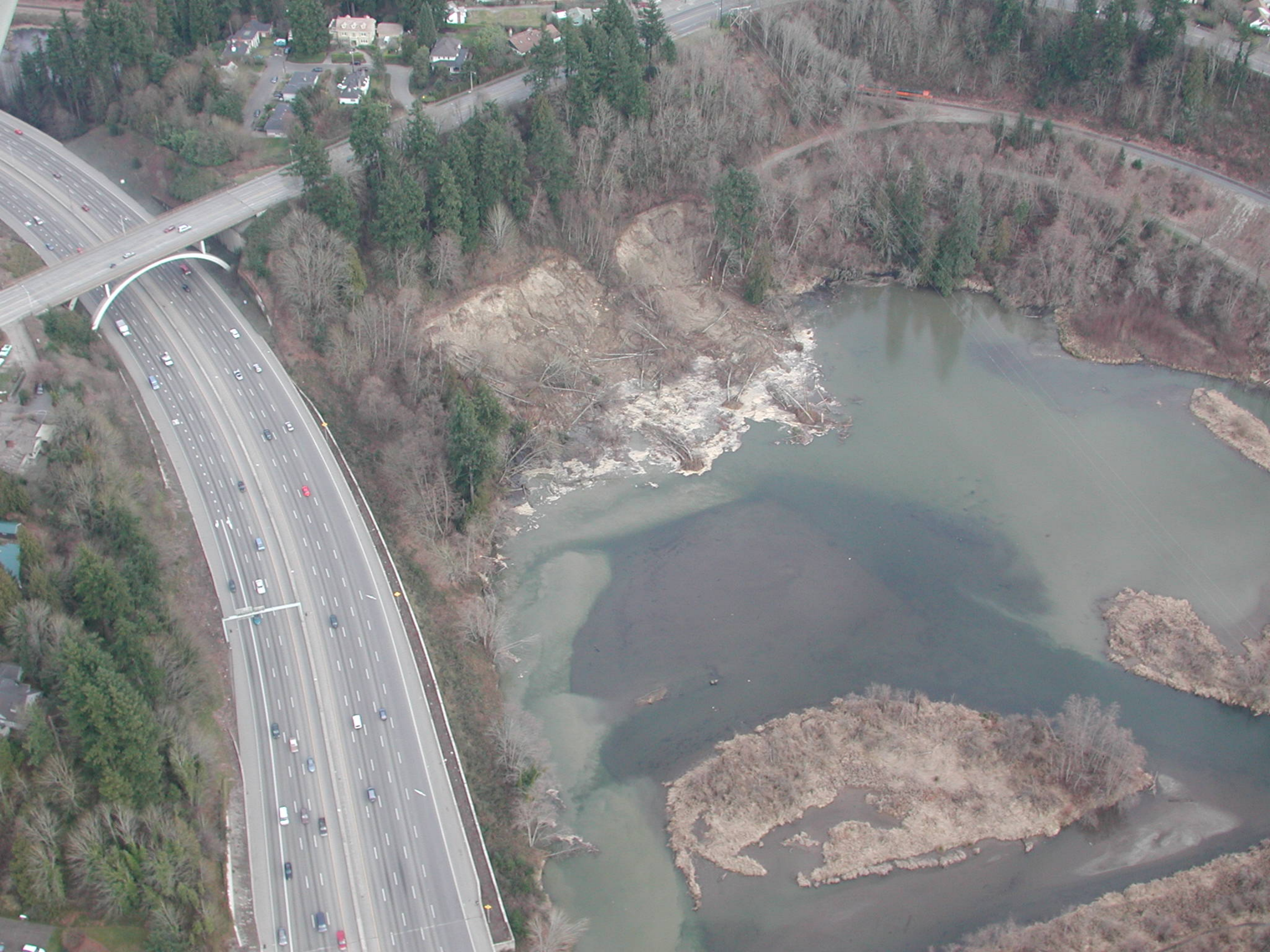


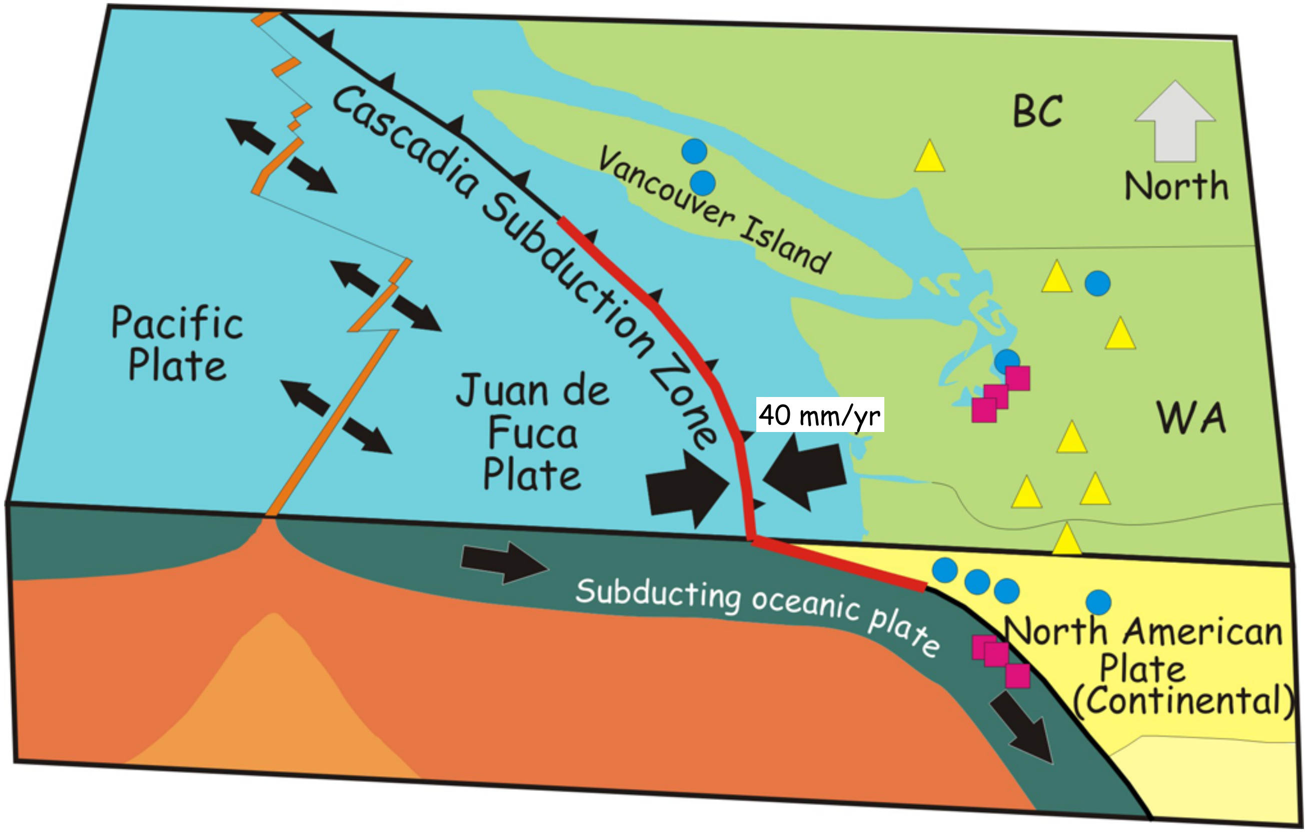
PROCESSED: Thu Apr 19, 2001 03:39:38 AM PDT,



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+







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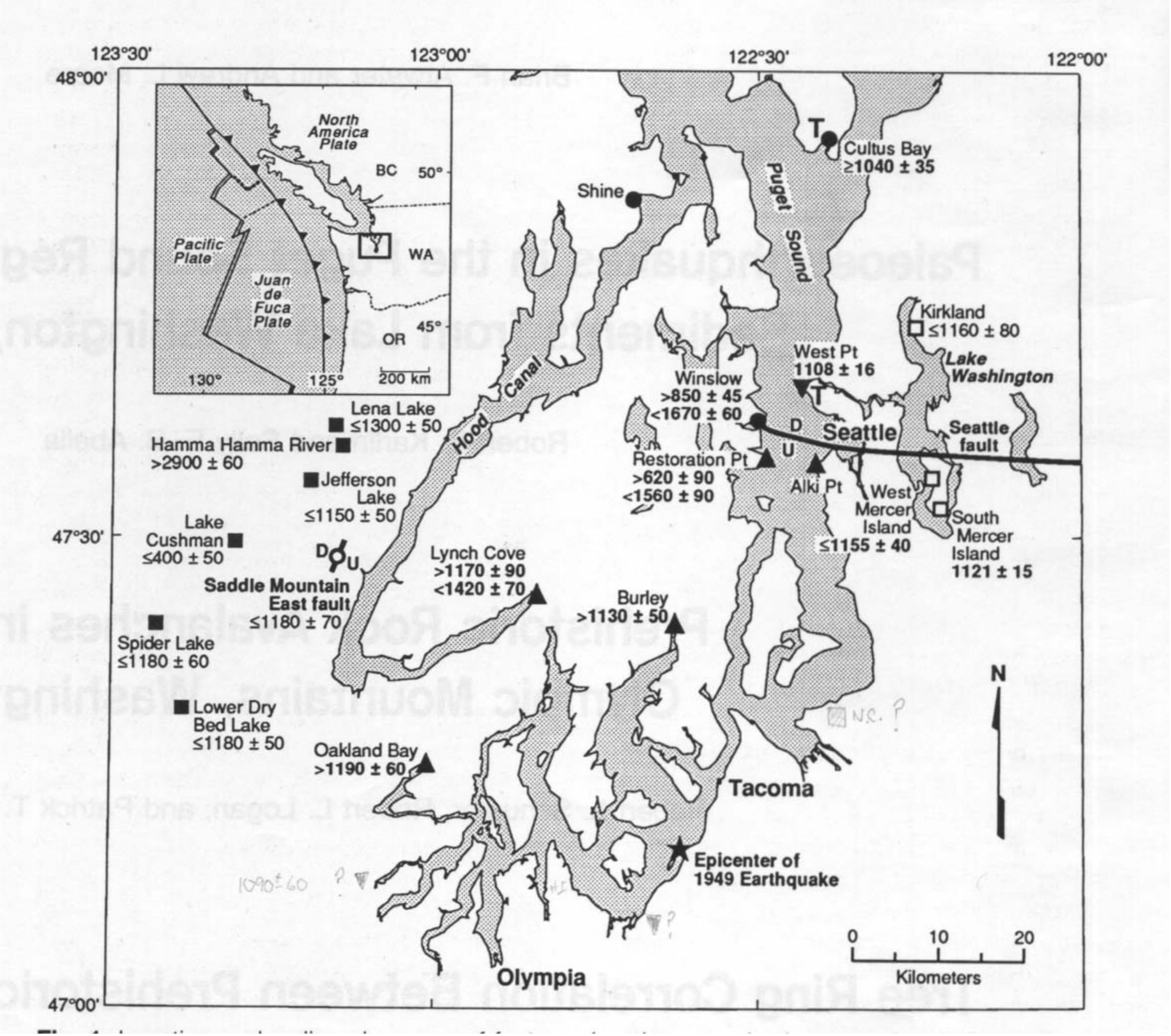
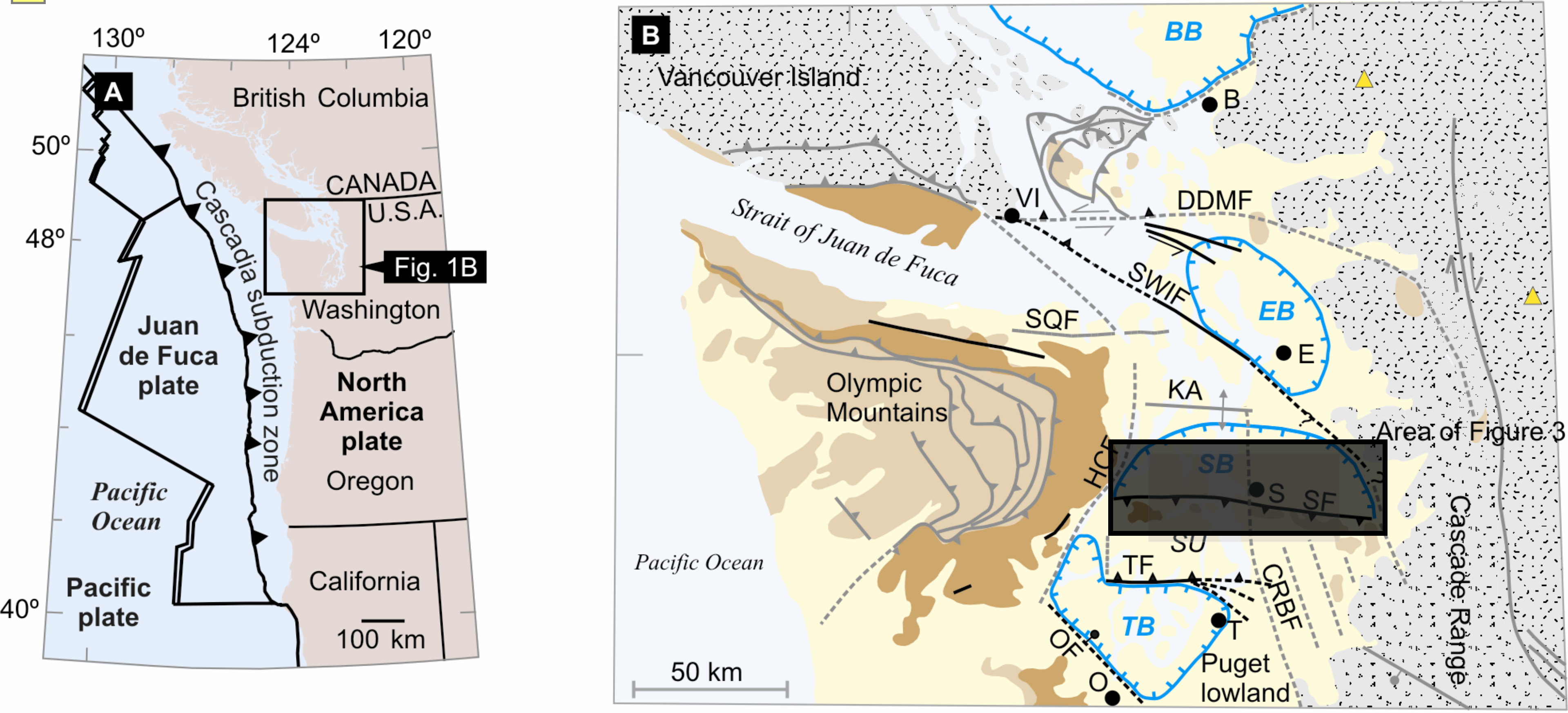


(from Bucknam et al., Science, vol. 258, 1992)



Structural basin

Thrust fault (teeth on upthrown block), black where Holocene movement is known or suspected

Fault, black where Holocene movement is known or suspected

Fault (bar and ball on downthrown side), black where Holocene movement is known or suspected

Concealed fault, black where Holocene movement is known or suspected

Quaternary deposits

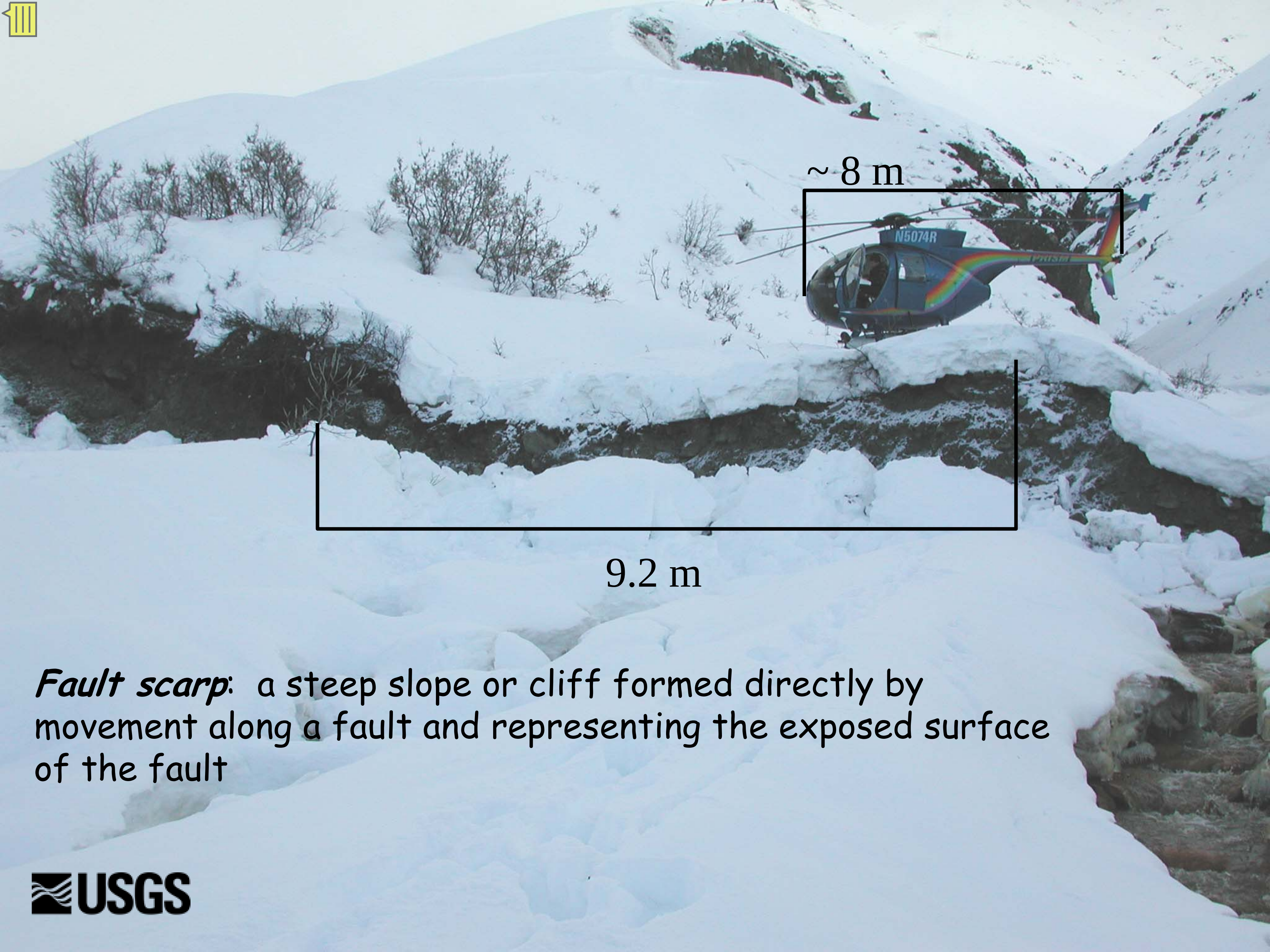
Sedimentary rocks (Paleogene to Neogene)

Cascade igneous rocks (Oligocene and younger)

Crescent Formation and other Eocene volcanic rocks

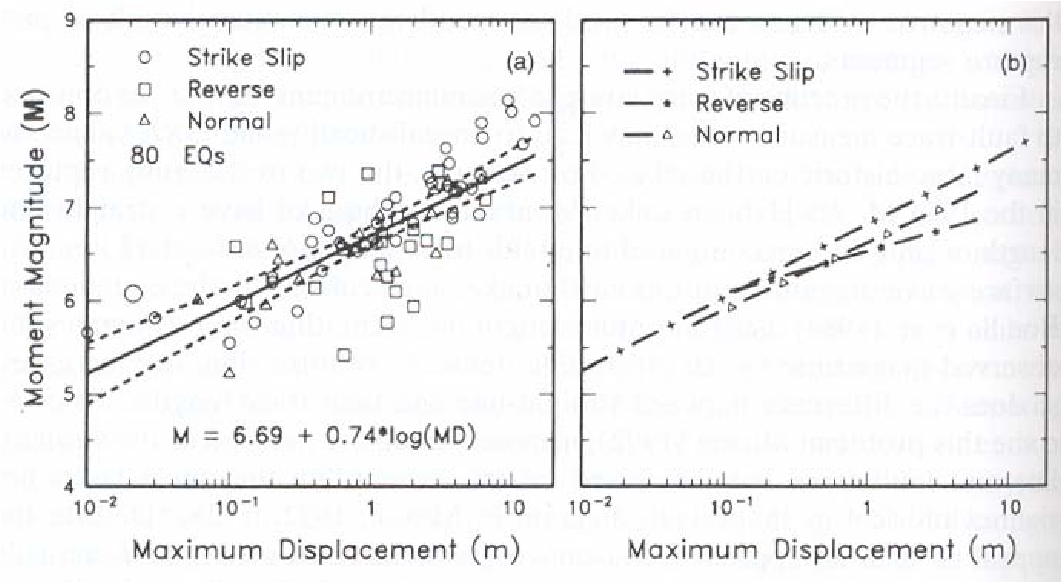
Basement rocks (pre-Tertiary)

▲ Quaternary volcano

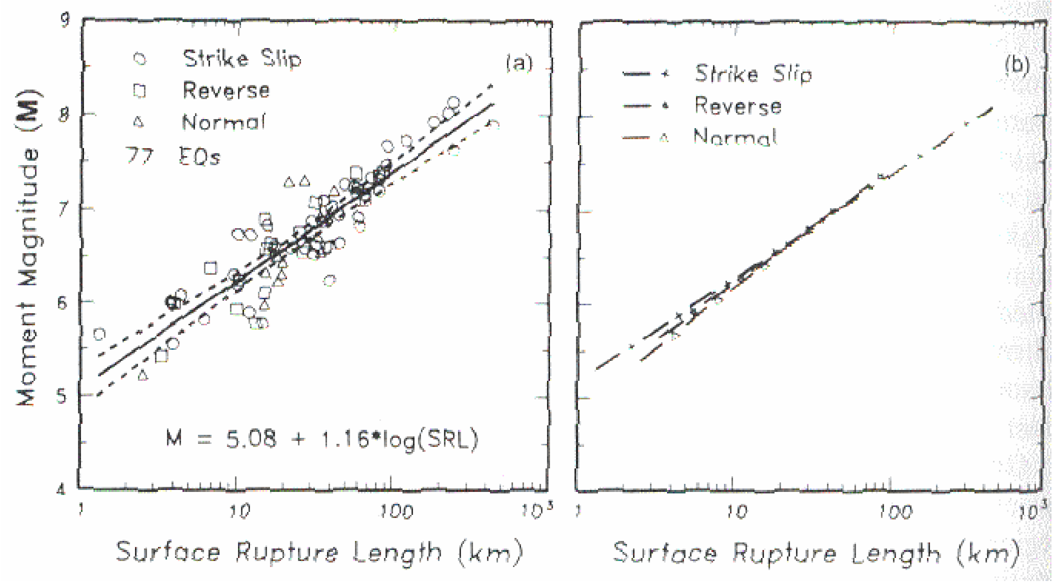


Fault scarp: a steep slope or cliff formed directly by movement along a fault and representing the exposed surface of the fault

Why bother?



9
8
7
6
5
4
Moment Magnitude (M)
Strike Slip
Reverse
Normal
80 EQs
(a)
M = 6.69 + 0.74*log(MD)
10^-2
10^-1
1
10
Maximum Displacement (m)
(b)
Strike Slip
Reverse
Normal
10^-2
10^-1
1
10
Maximum Displacement (m)

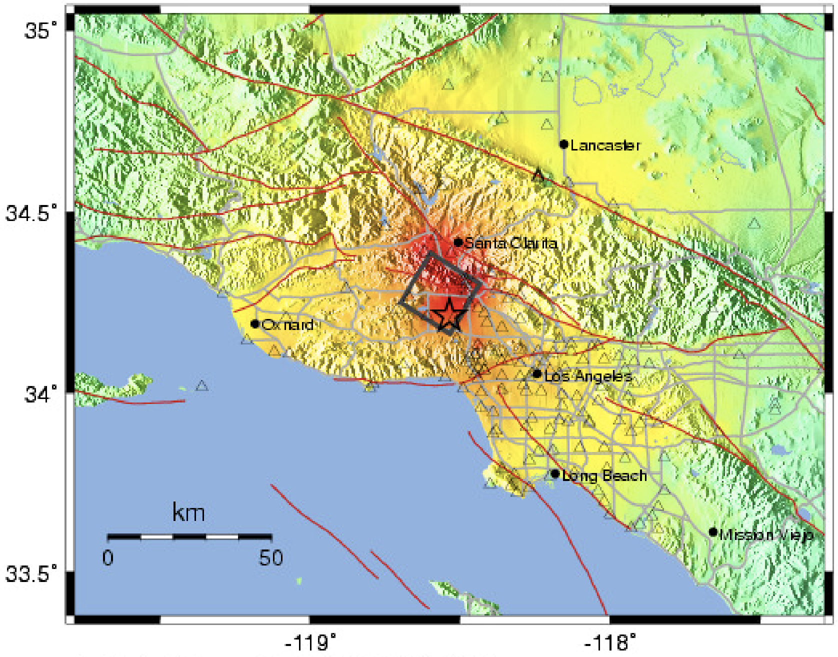


9
8
7
6
5
4
Moment Magnitude (M)
Strike Slip
Reverse
Normal
77 EQs
(a)
M = 5.08 + 1.16*log(SRL)
1
10
100
10^3
Surface Rupture Length (km)
(b)
Strike Slip
Reverse
Normal
1
10
100
10^3
Surface Rupture Length (km)

Northridge M6.7
Depth = 18 km

CISN ShakeMap for Northridge Earthquake

Mon Jan 17, 1994 04:30:55 AM PST M 6.7 N34.21 W118.54 Depth: 18.0km ID:Northridge



Map Version 15 Processed Thu Feb 1, 2007 03:11:01 PM PST,

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
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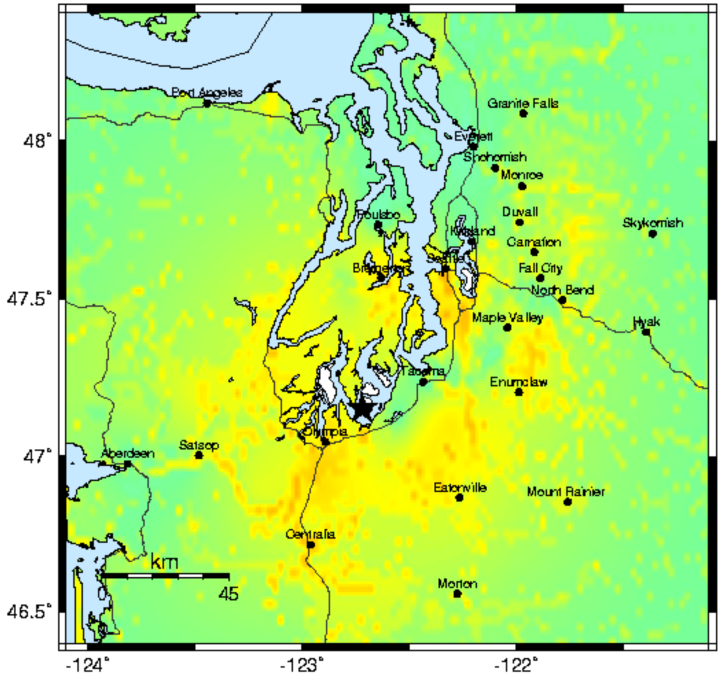
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Nisqually M6.8
Depth = 58 km

PNSN Rapid Instrumental Intensity Map Epicenter: 17.6 km NE of Olympia, WA

Wed Feb 28, 2001 10:54:00 AM PST M 6.8 N47.15 W122.72 ID:0102281854



PROCESSED: Thu Apr 19, 2001 03:39:38 AM PDT,

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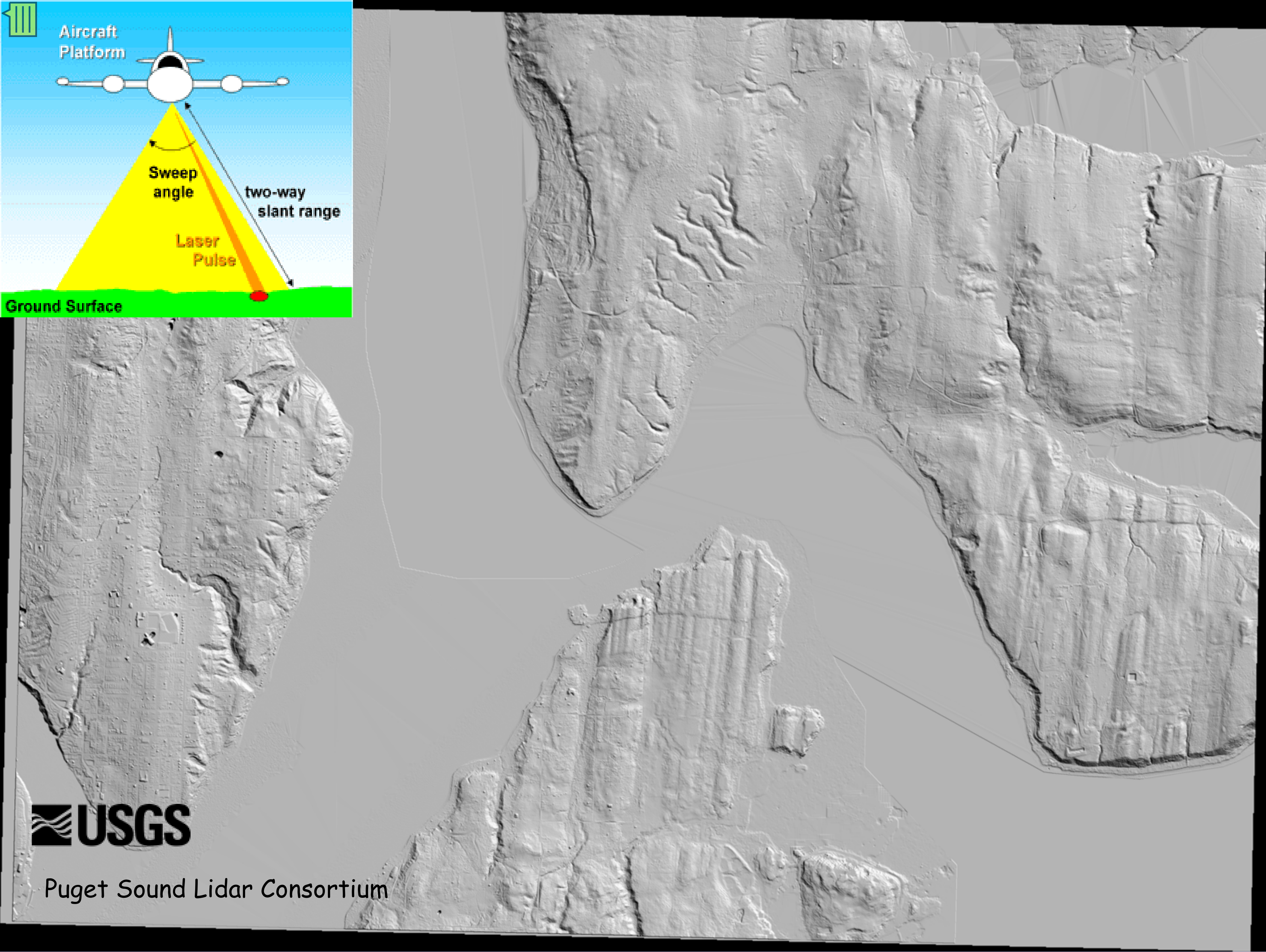
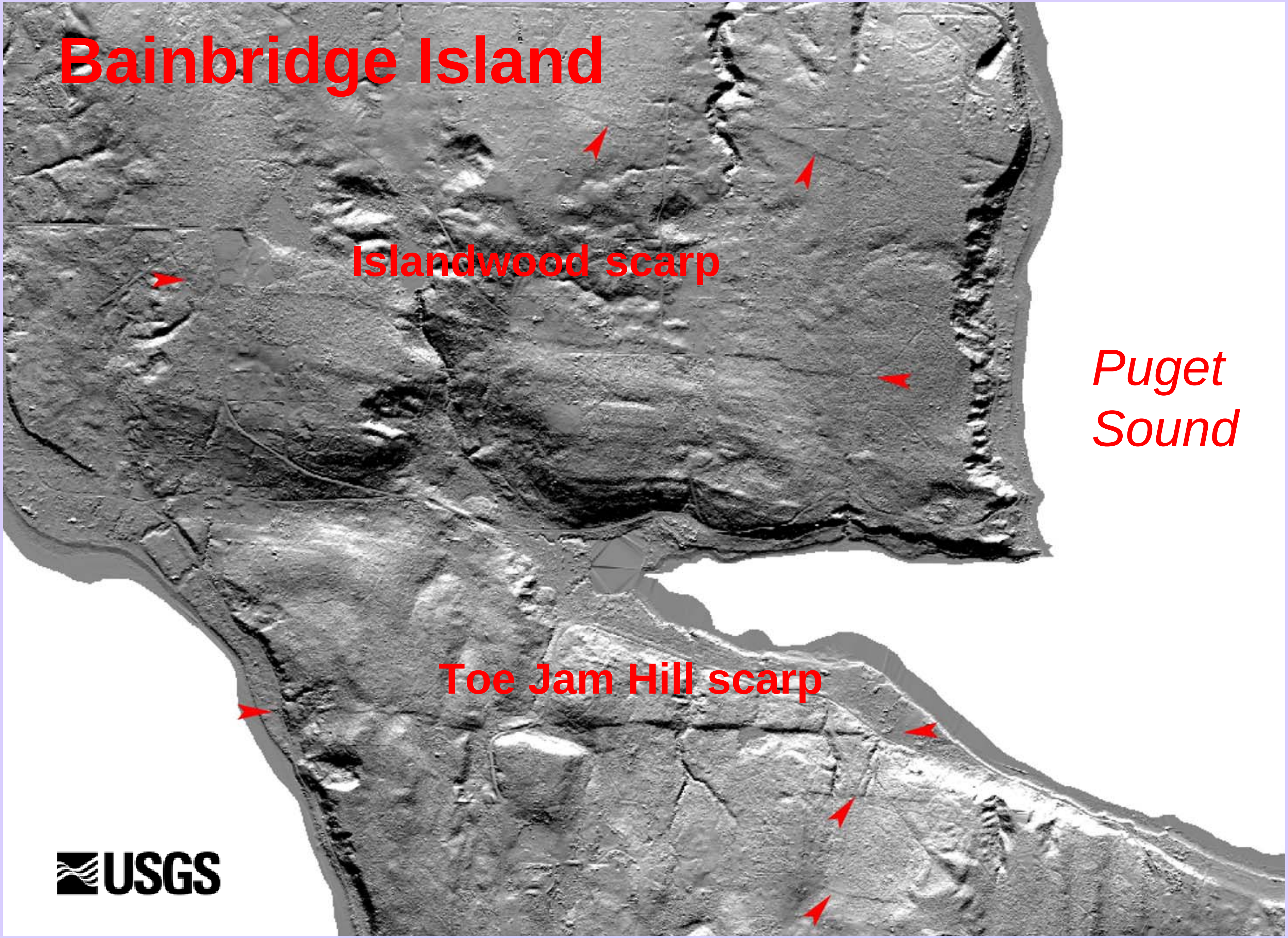
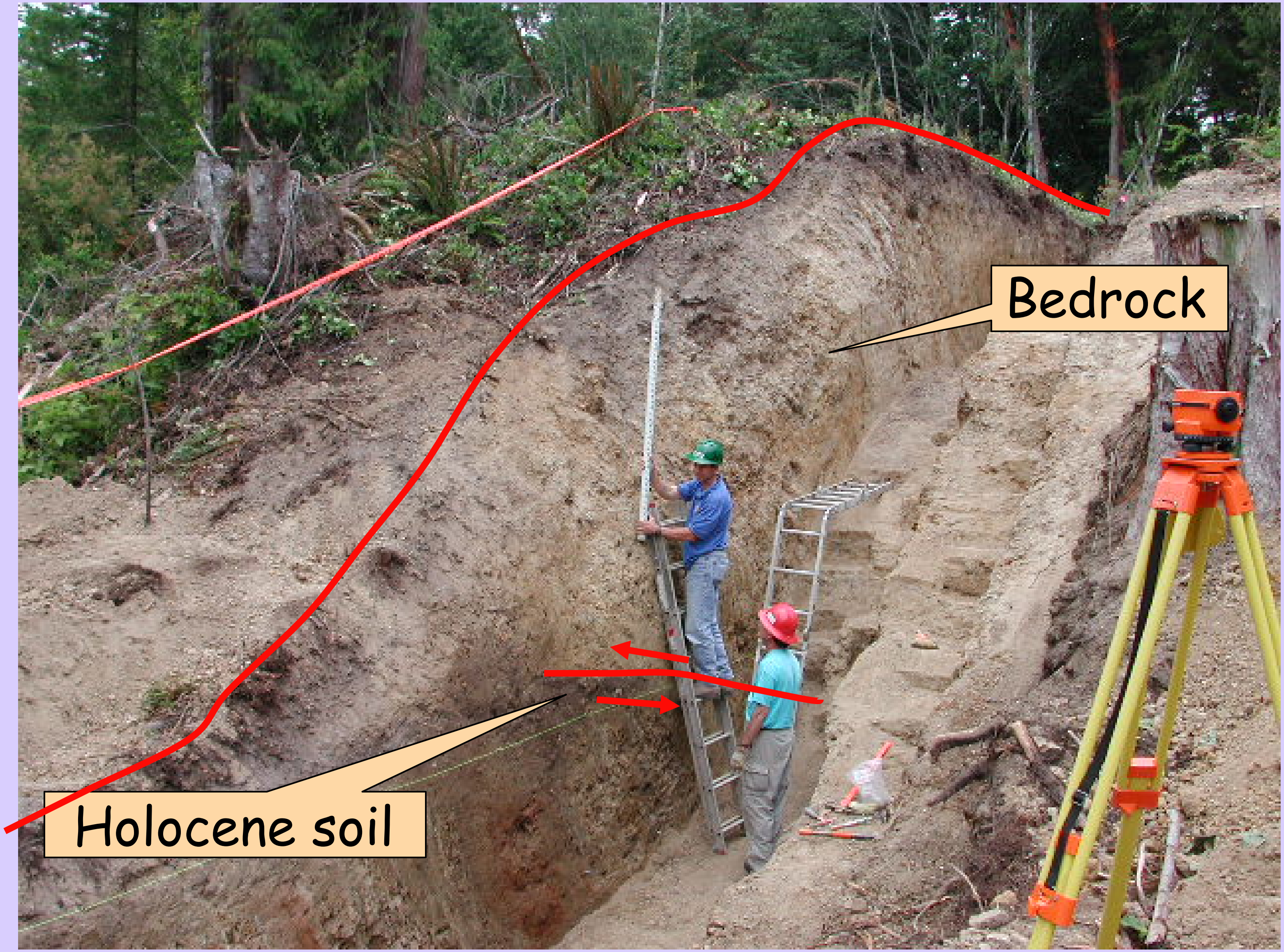
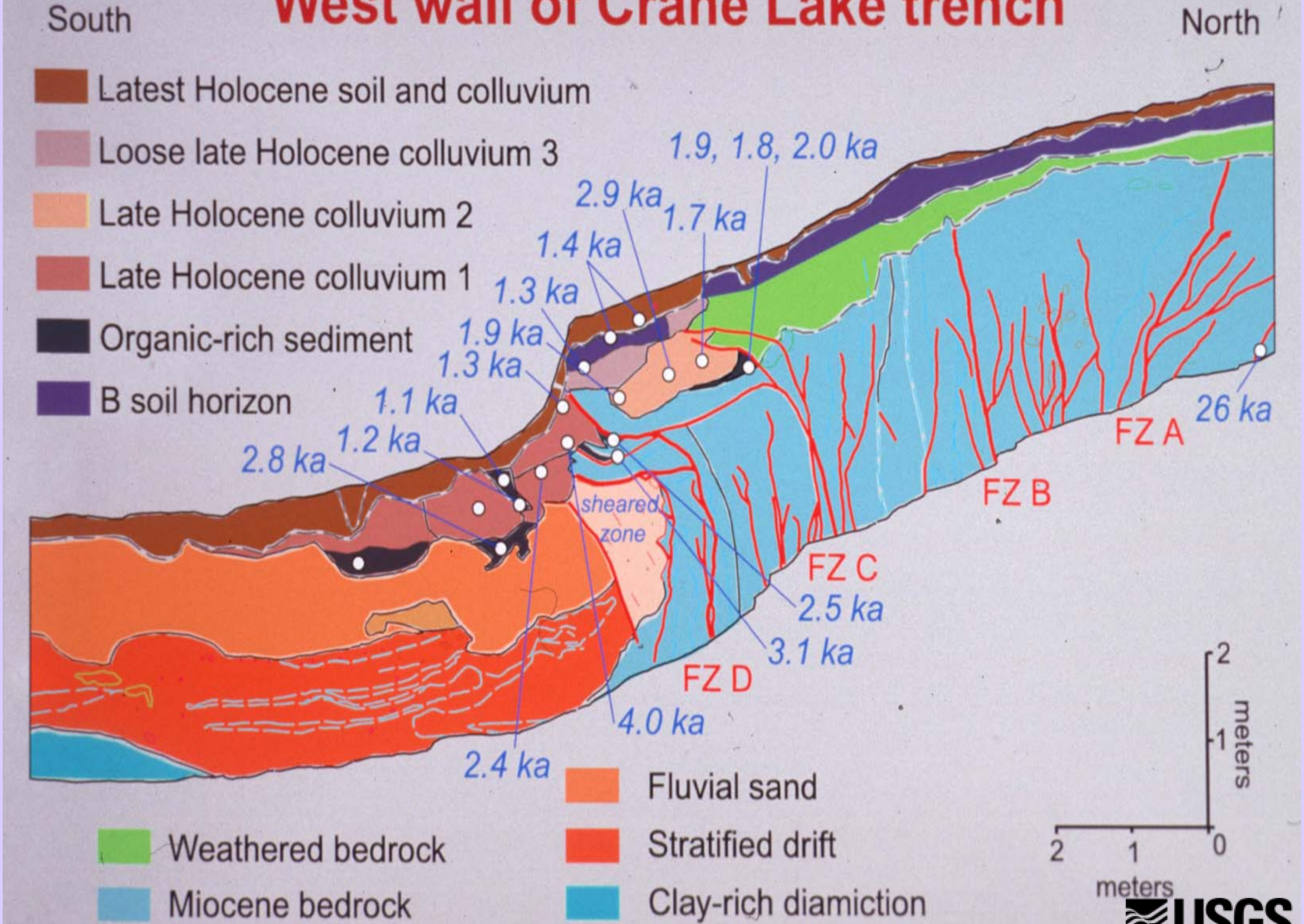


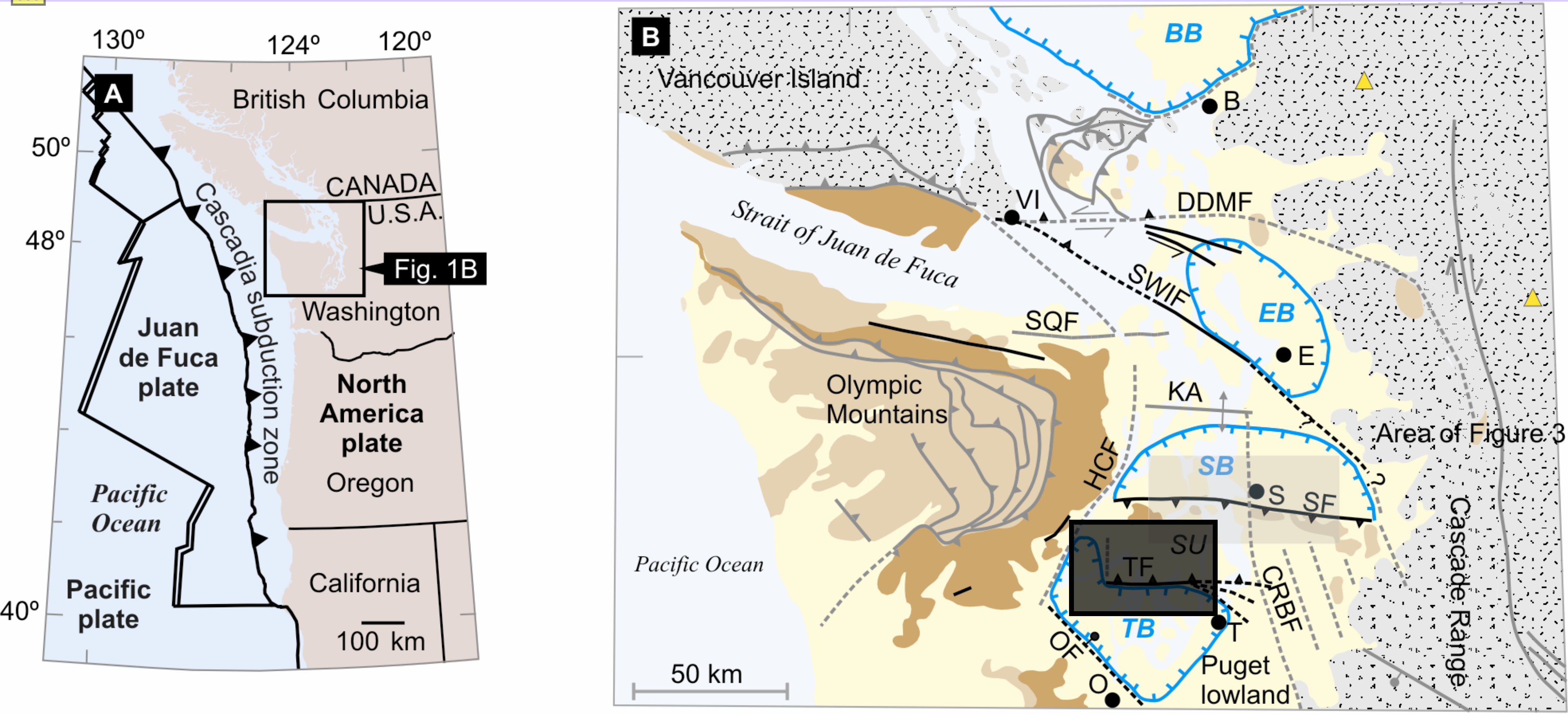
Puget Sound Lidar Consortium


Bainbridge Island
Islandwood scarp
Puget Sound
Toe Jam Hill scarp


Bedrock
Holocene soil

West wall of Crane Lake trench





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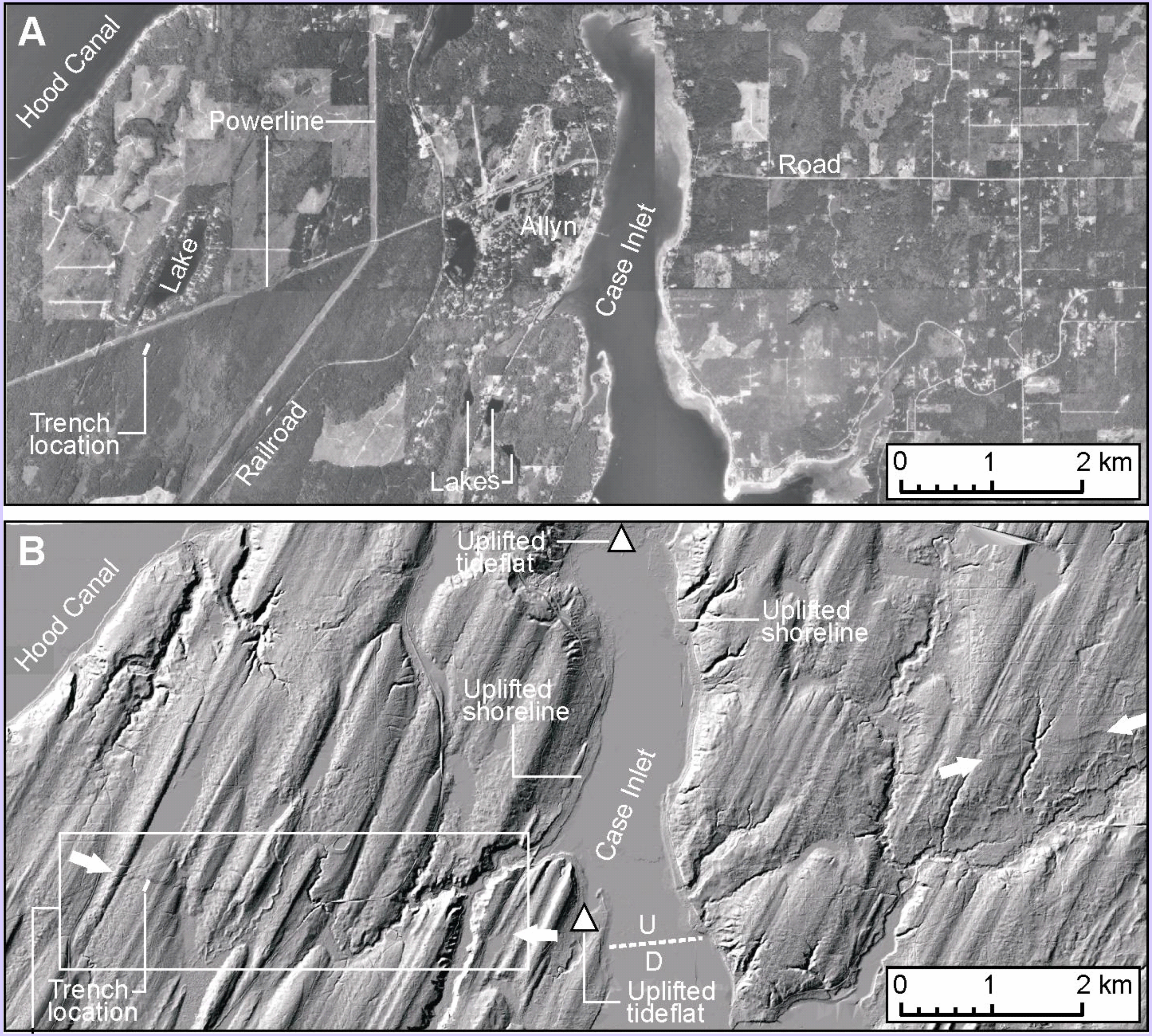
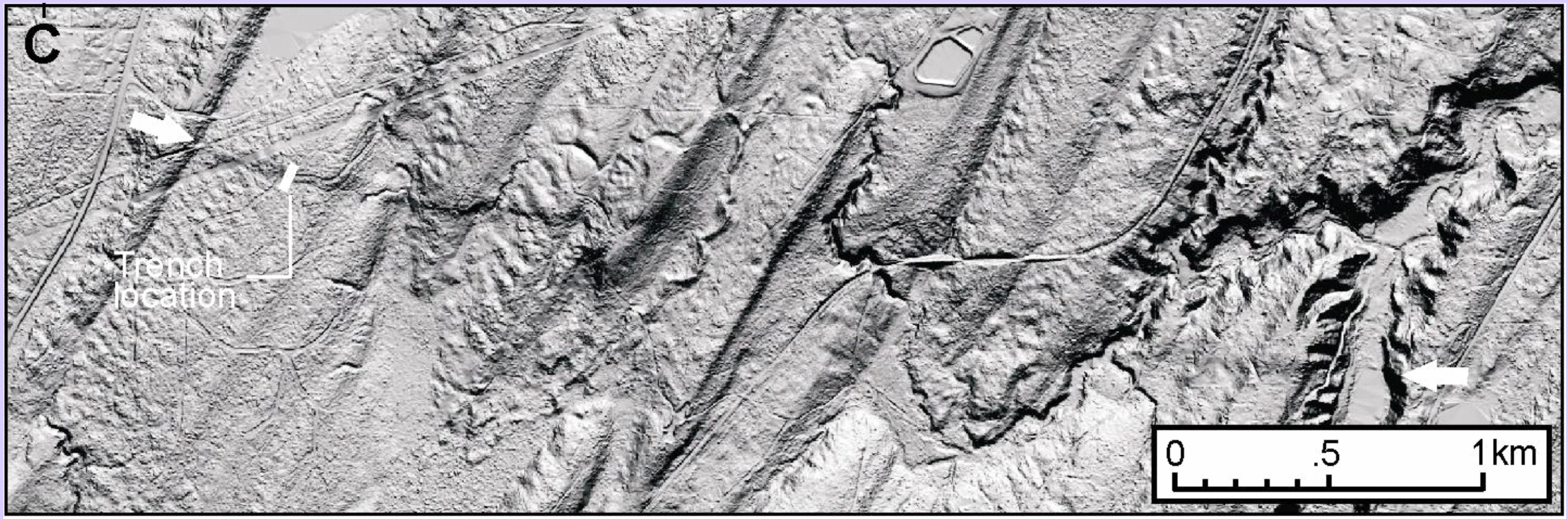
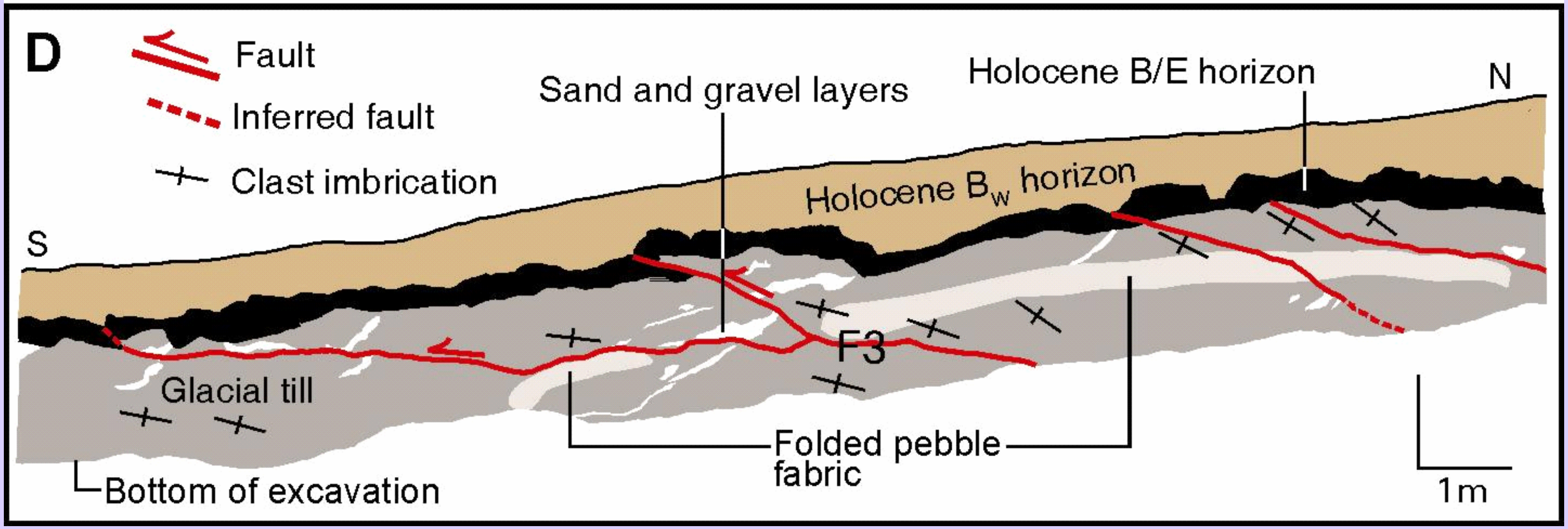
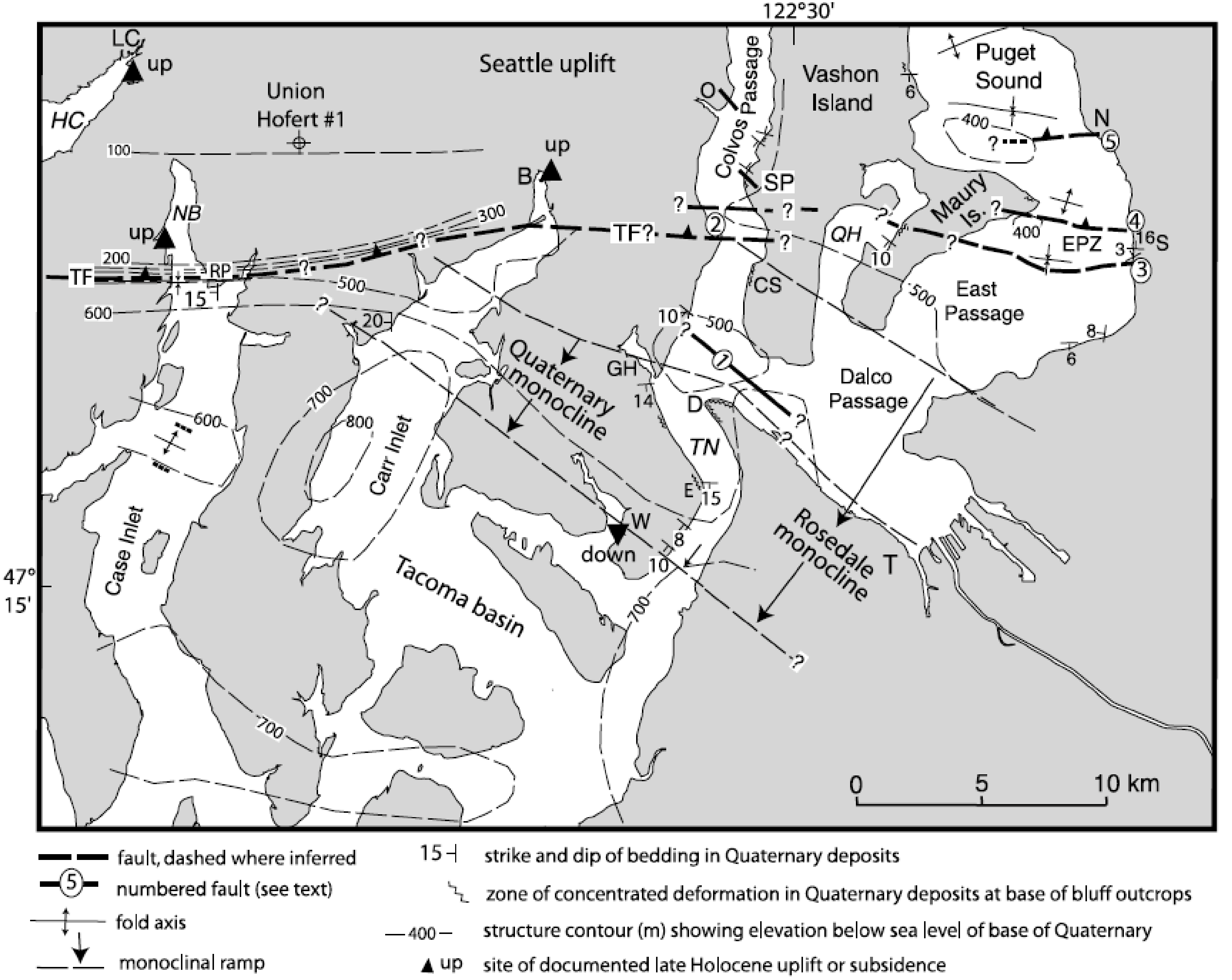

A
Hood Canal
Powerline
Lake
Allyn
Case Inlet
Road
Trench location
Railroad
Lakes
0 1 2 km
B
Hood Canal
Uplifted tideflat
Uplifted shoreline
Uplifted shoreline
Case Inlet
U
D
Trench location
Uplifted tideflat
0 1 2 km


C
Trench location
0
.5
1 km


D
Fault
Inferred fault
Clast imbrication
Sand and gravel layers
Holocene B/E horizon
N
S
Holocene B_w horizon
F3
Glacial till
Folded pebble fabric
Bottom of excavation
1 m


122°30'
47° 15'
Seattle uplift
Union Hofert #1
Vashon Island
Puget Sound
Colvos Passage
Maury Is.
East Passage
Dalco Passage
Quaternary monocline
Rosedale monocline
Carr Inlet
Case Inlet
Tacoma basin
LC
HC
NB
B
RP
TF
TF?
O
SP
QH
CS
GH
D
TN
E
W
T
N
S
EPZ
up
down
100
200
300
400
500
600
700
800
0 5 10 km
fault, dashed where inferred
numbered fault (see text)
fold axis
monoclinal ramp
strike and dip of bedding in Quaternary deposits
zone of concentrated deformation in Quaternary deposits at base of bluff outcrops
structure contour (m) showing elevation below sea level of base of Quaternary
site of documented late Holocene uplift or subsidence

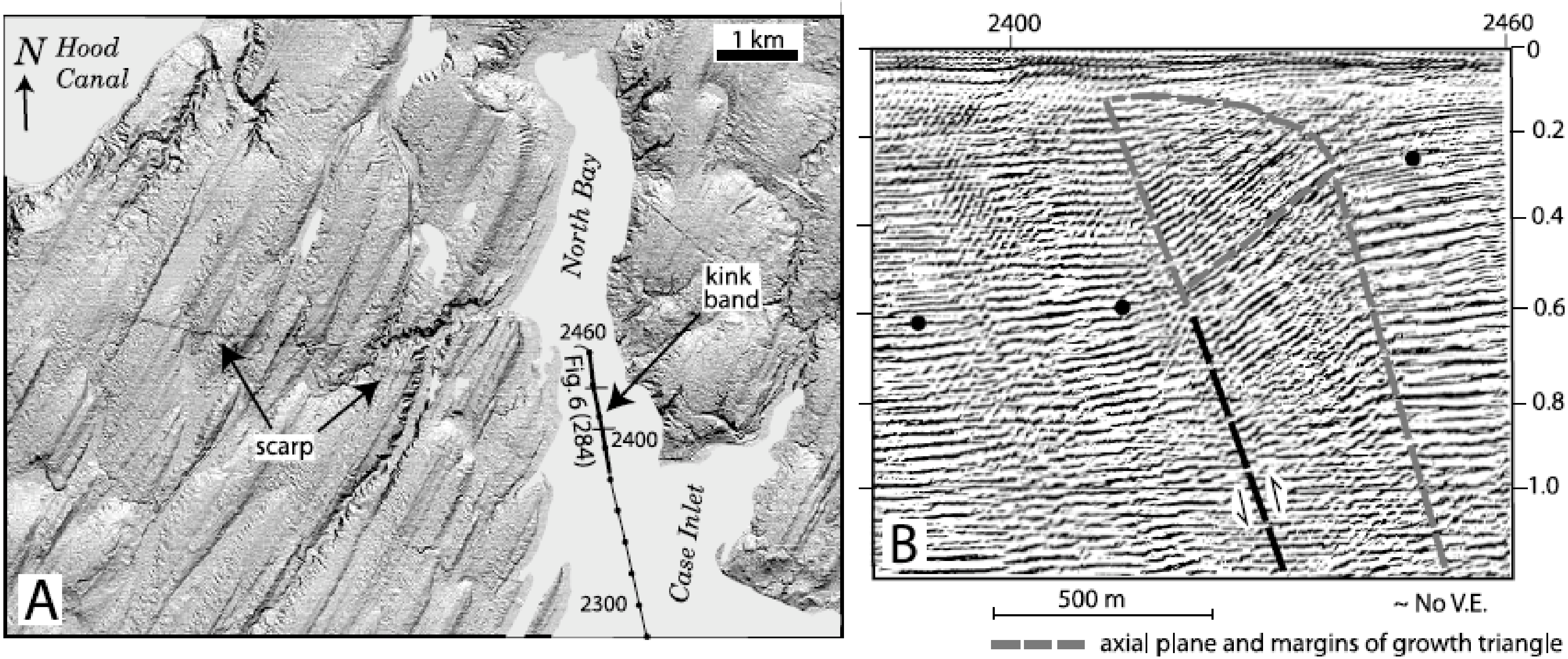
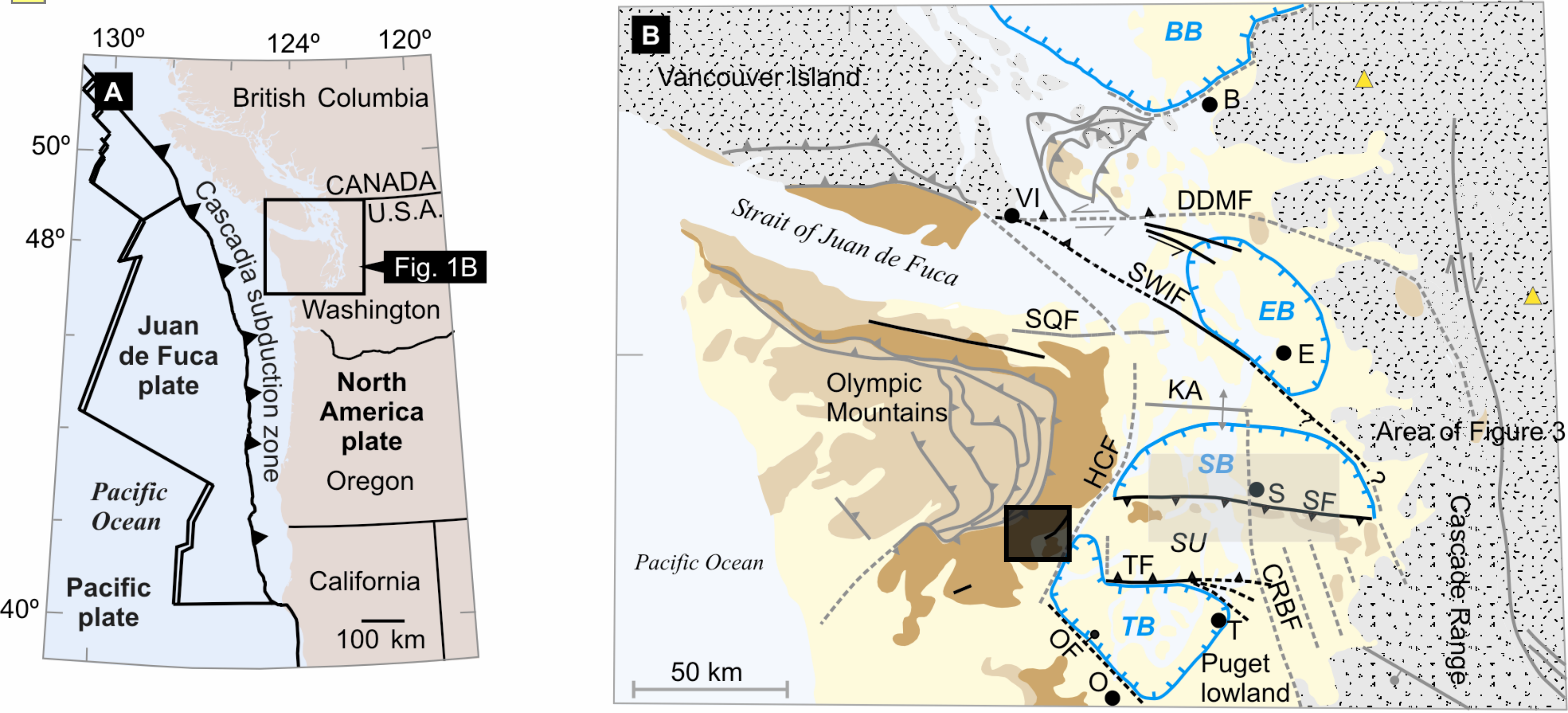


Figure 7. (a) Shot point map for USGS seismic reflection profile 284 (Figures 3 and 6) plotted on digital elevation model (DEM) derived from airborne laser swath mapping survey in the northern Case Inlet-North Bay area (Figure 3a). Note that a north-side-up, west trending scarp lies along strike with the upper hinge of the kink band imaged on line 284 (Figures 6 and 7b). Prominent north-northeast lineations on the landscape are of glacial origin. (b) Northern part of USGS profile 284 showing kink band.



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▨ Sedimentary rocks (Paleogene to Neogene)

☐ Cascade igneous rocks (Oligocene and younger)

■ Crescent Formation and other Eocene volcanic rocks

☐ Basement rocks (pre-Tertiary)

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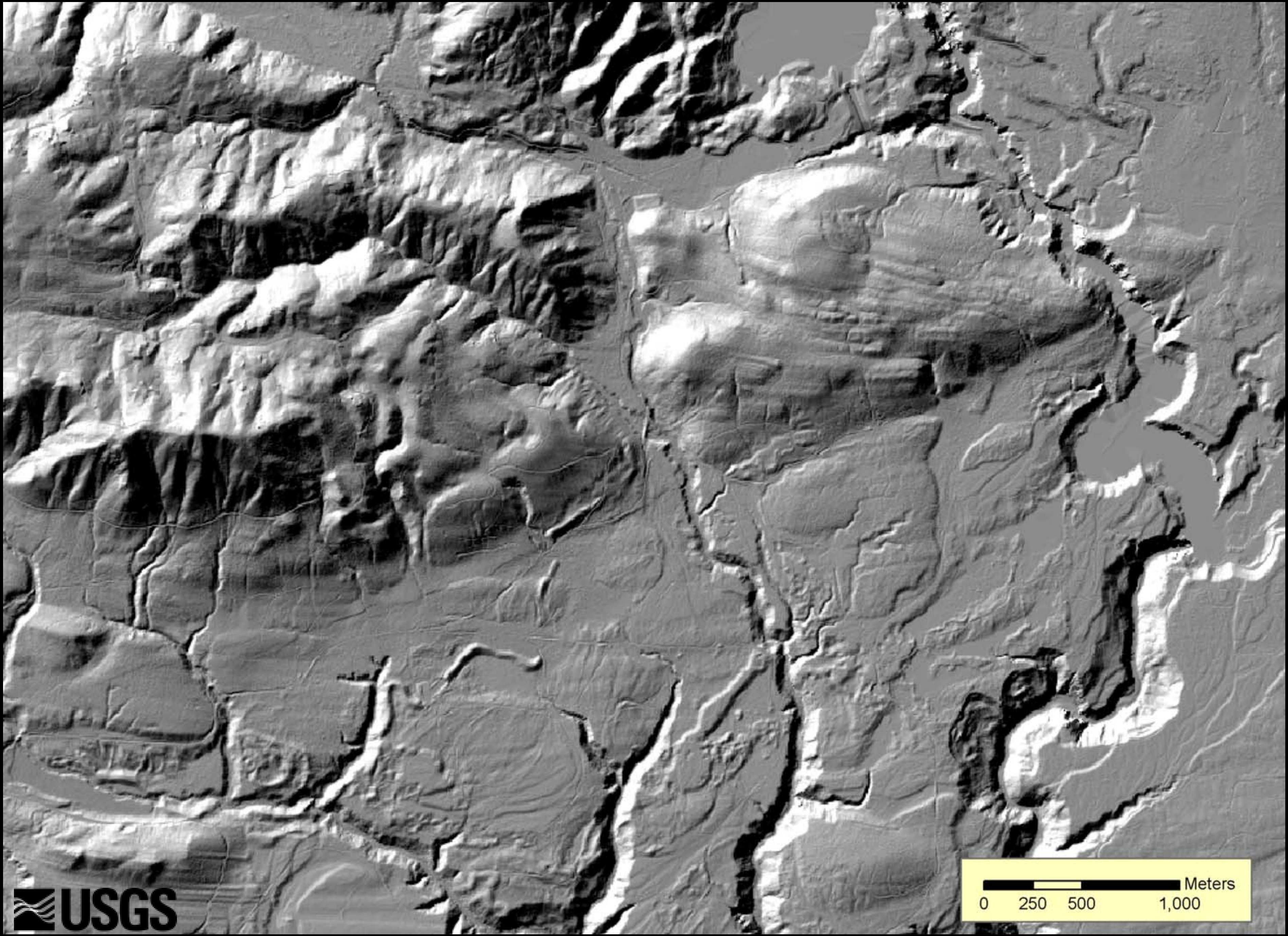
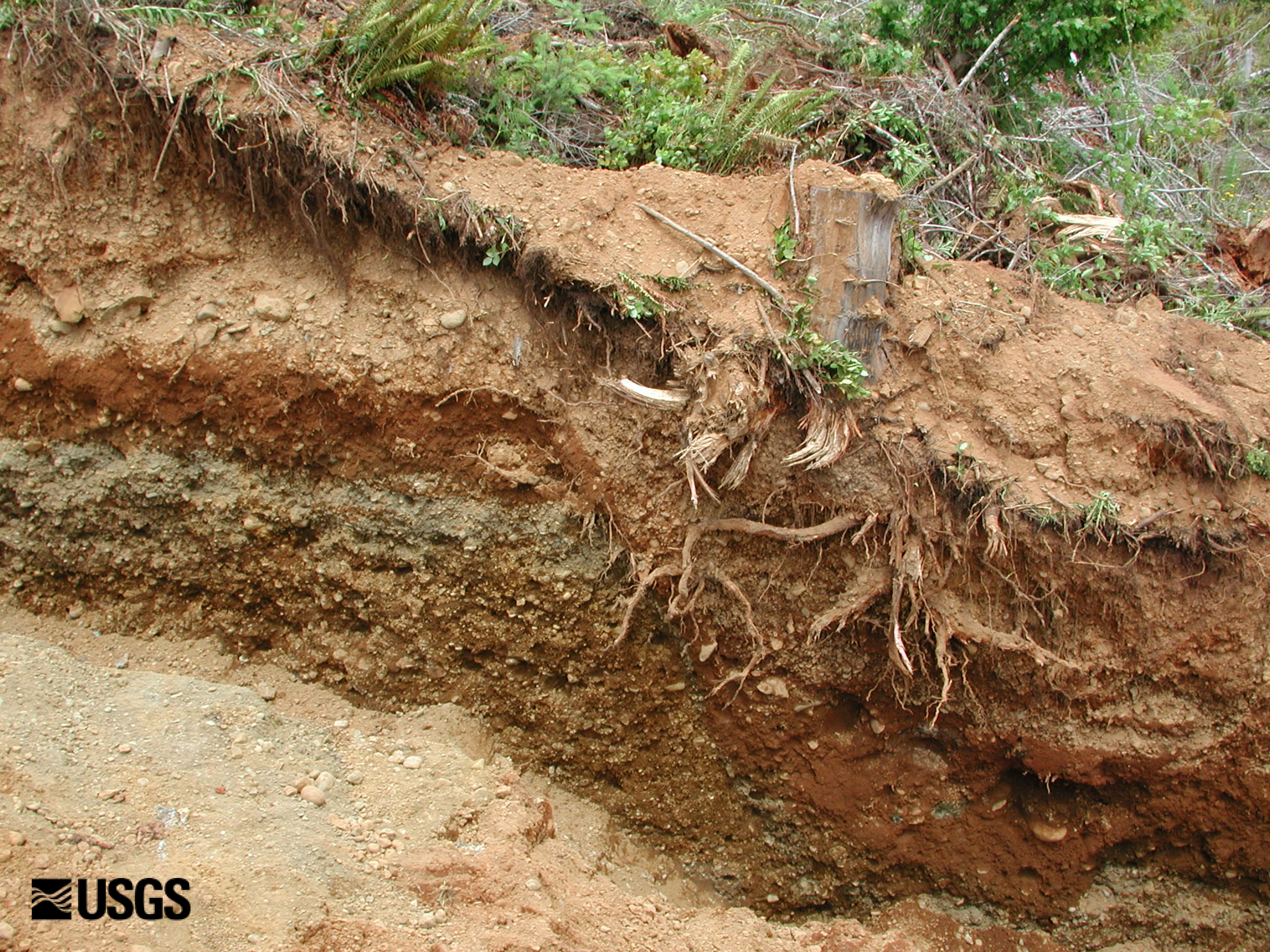
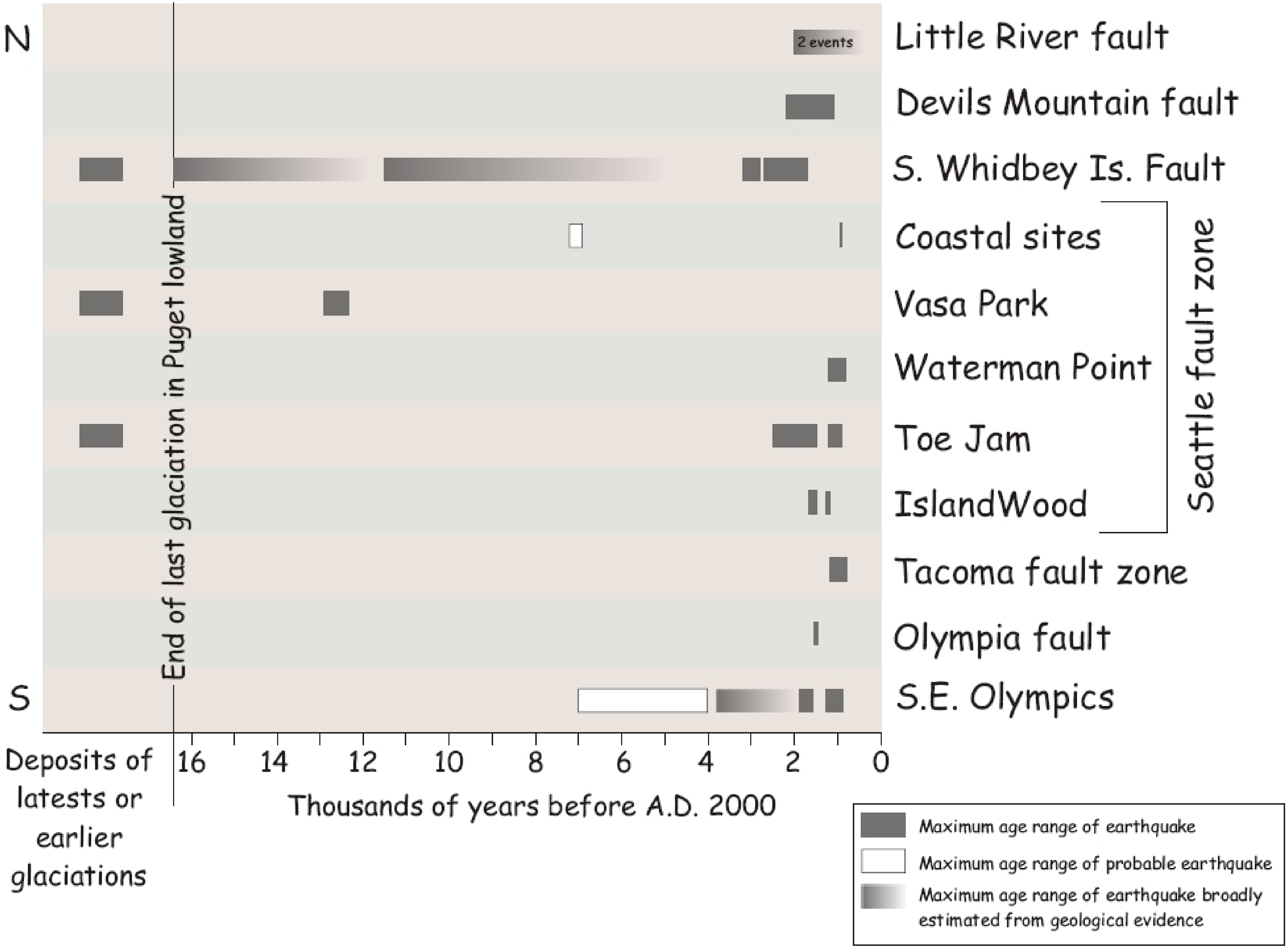

USGS
Meters
0
250
500
1,000

USGS

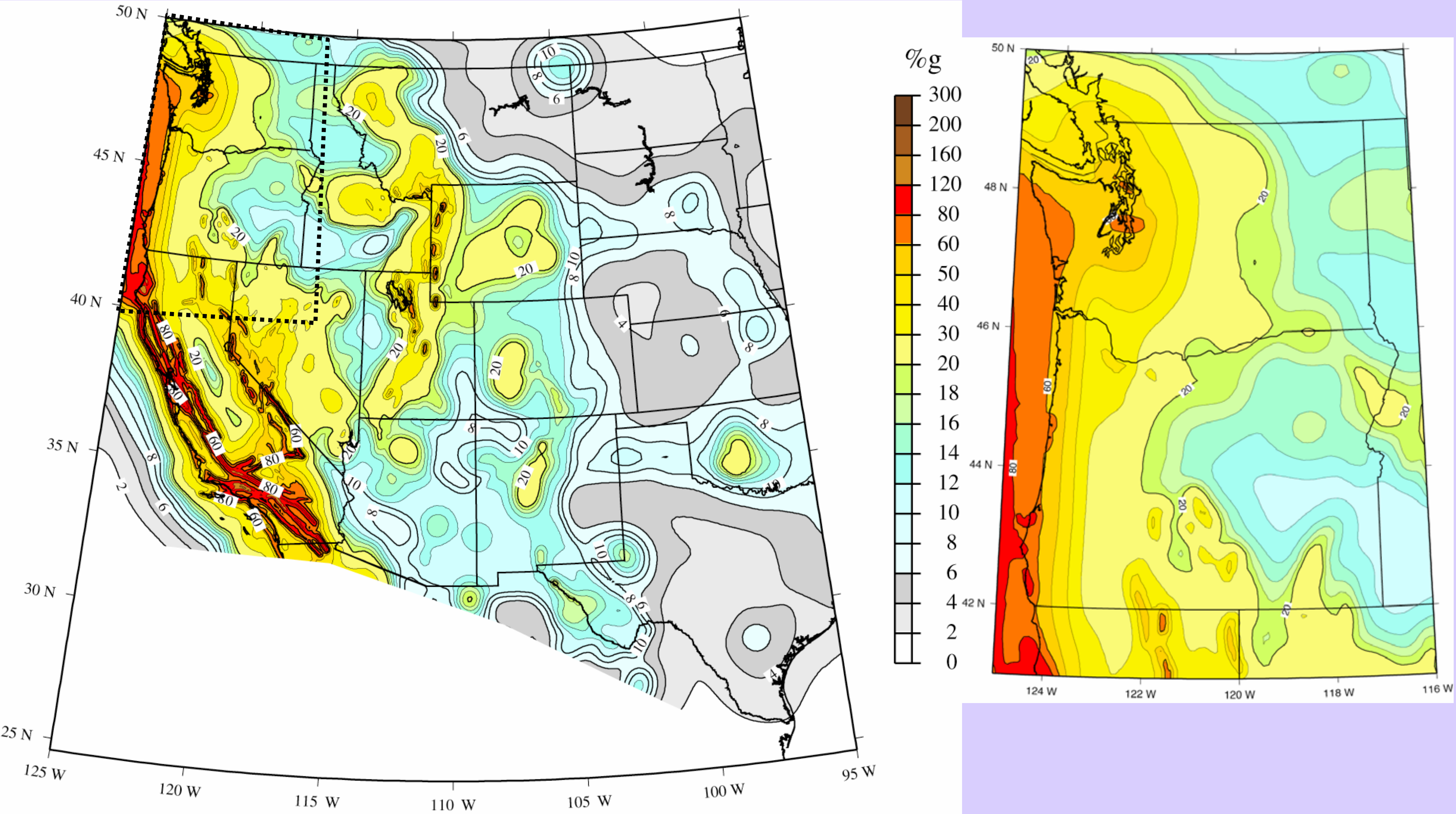



N
S
Little River fault
2 events
Devils Mountain fault
S. Whidbey Is. Fault
Coastal sites
Vasa Park
Waterman Point
Toe Jam
IslandWood
Seattle fault zone
Tacoma fault zone
Olympia fault
S.E. Olympics
End of last glaciation in Puget lowland
Deposits of latests or earlier glaciations
16
14
12
10
8
6
4
2
0
Thousands of years before A.D. 2000
Maximum age range of earthquake
Maximum age range of probable earthquake
Maximum age range of earthquake broadly estimated from geological evidence

How the research is put into practice…….

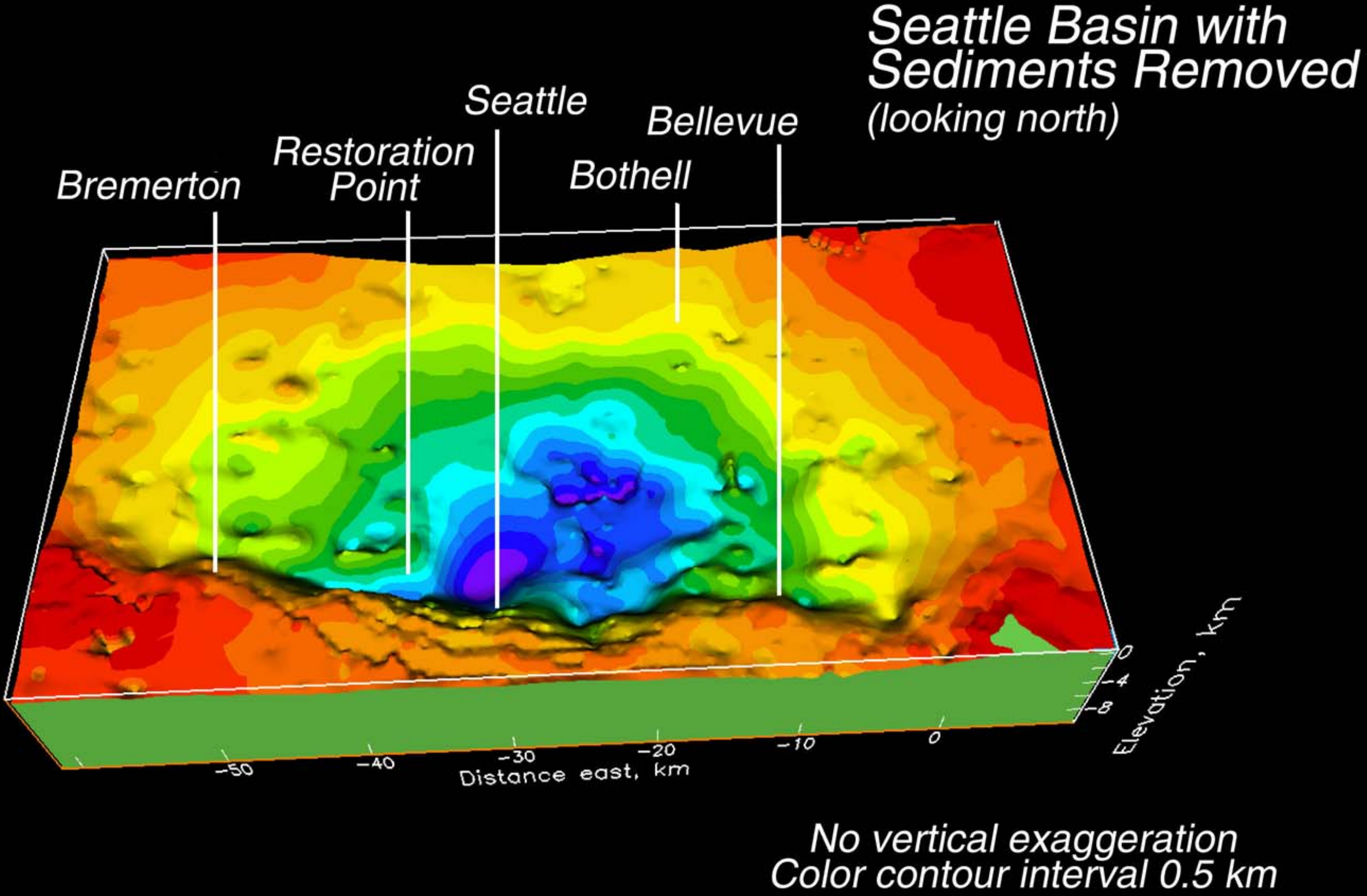
National Seismic Hazard Maps

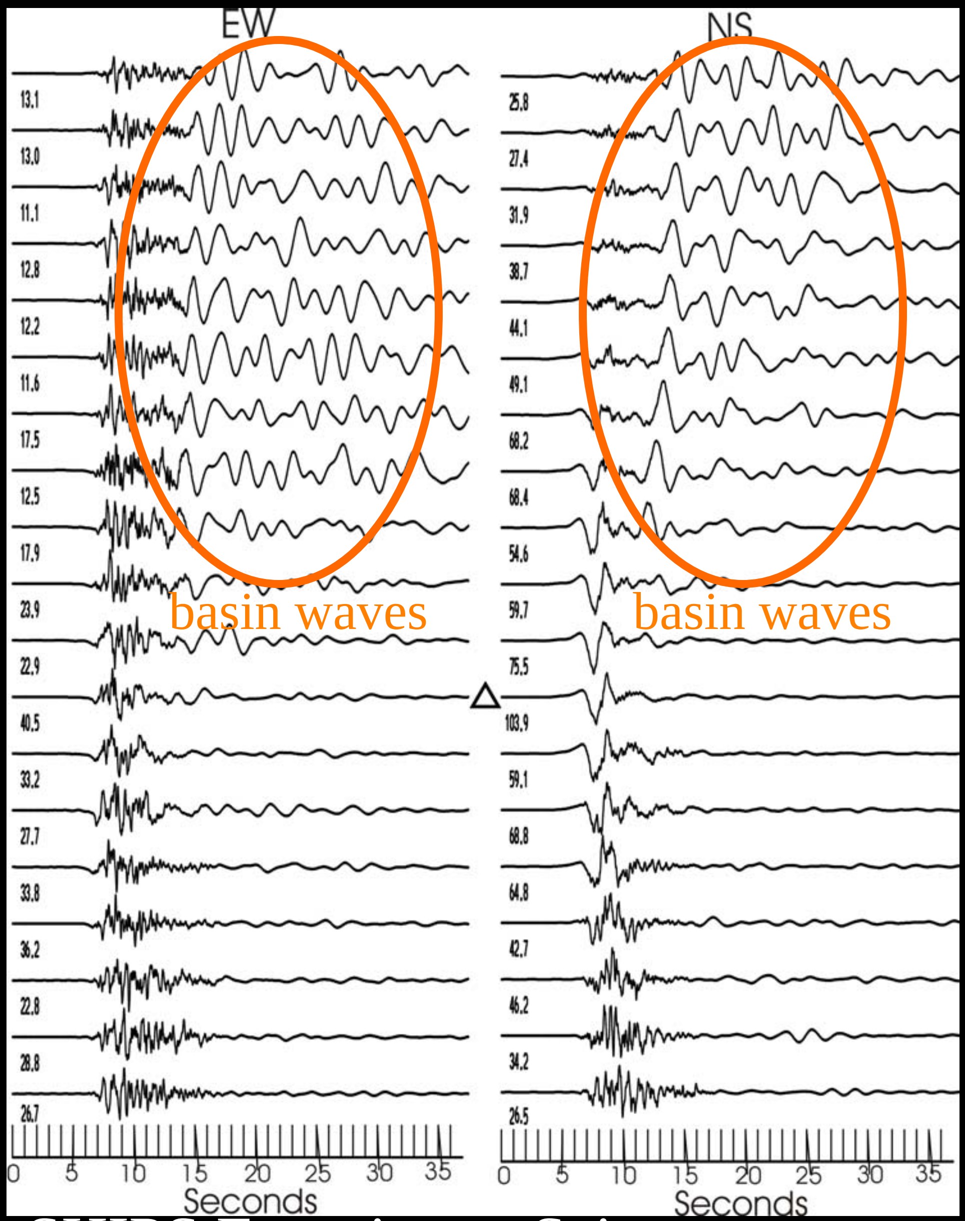
Peak Acceleration, 2% Probability of Exceedance in 50 Years



Used in building codes.

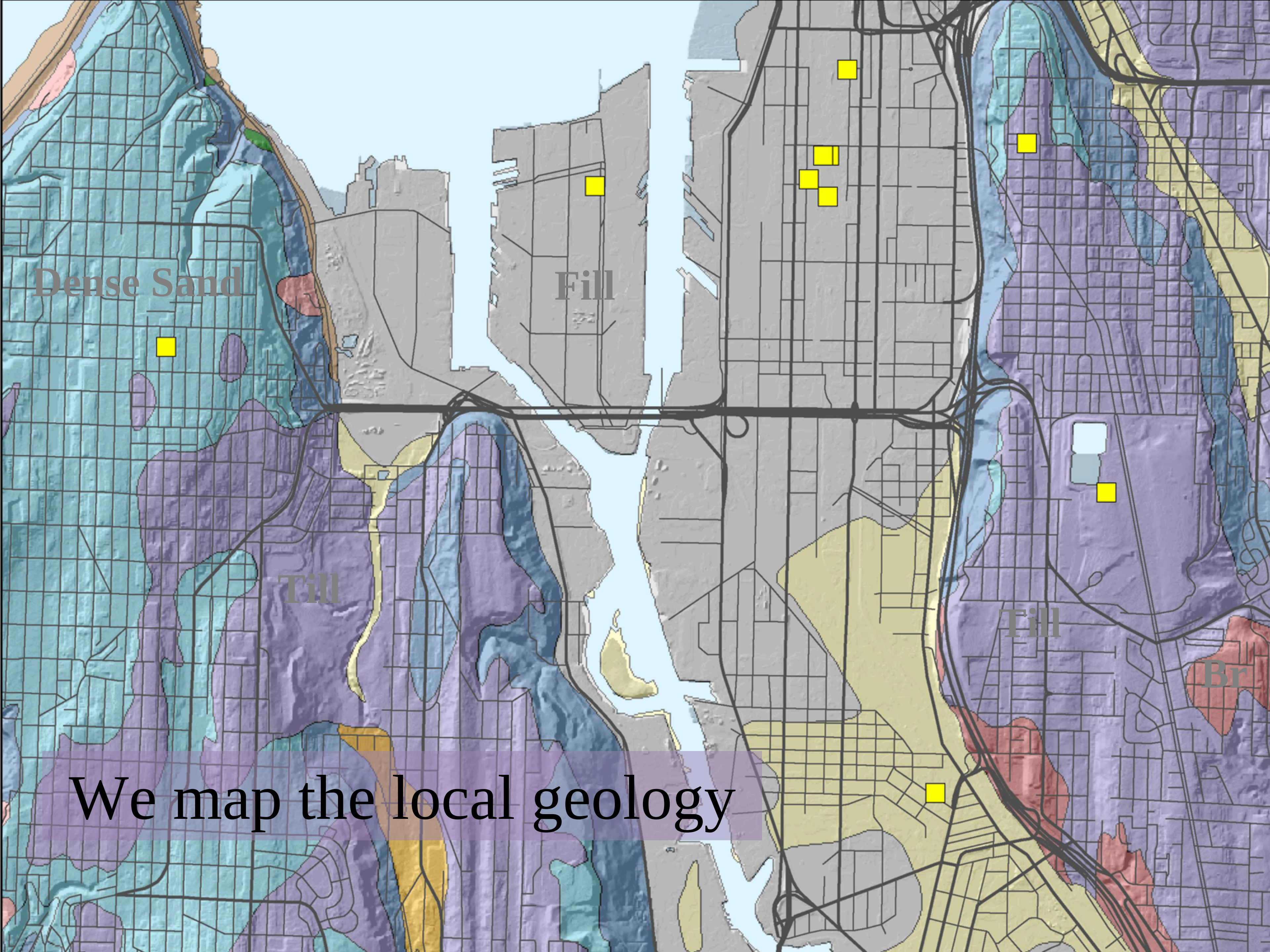
Local Geologic Structure is Important.



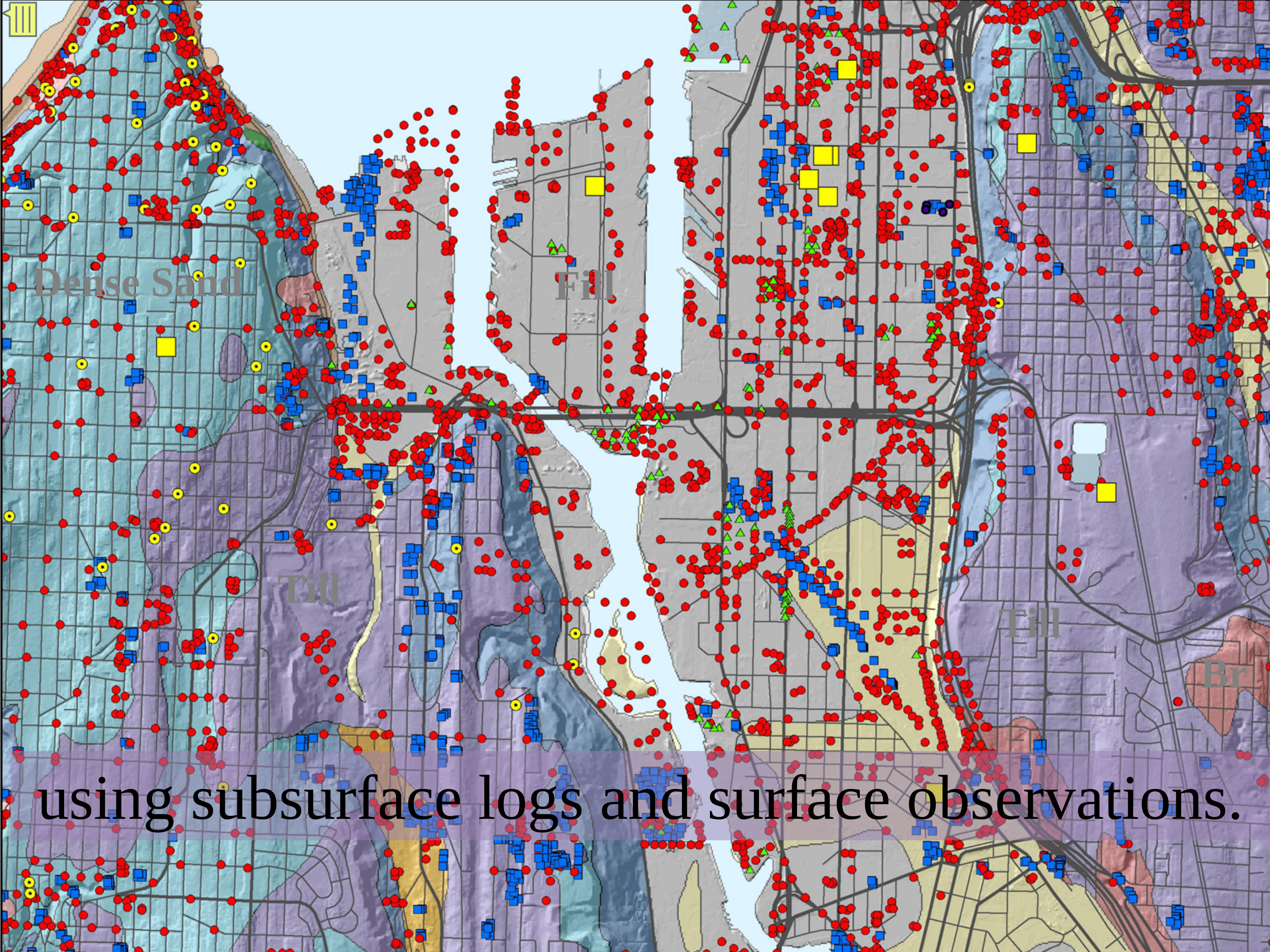


SHIPS Experiment Seismograms

Horizontal shaking from explosions recorded along a north-south line traversing the Seattle Basin, where sediments amplify and extend the shaking.



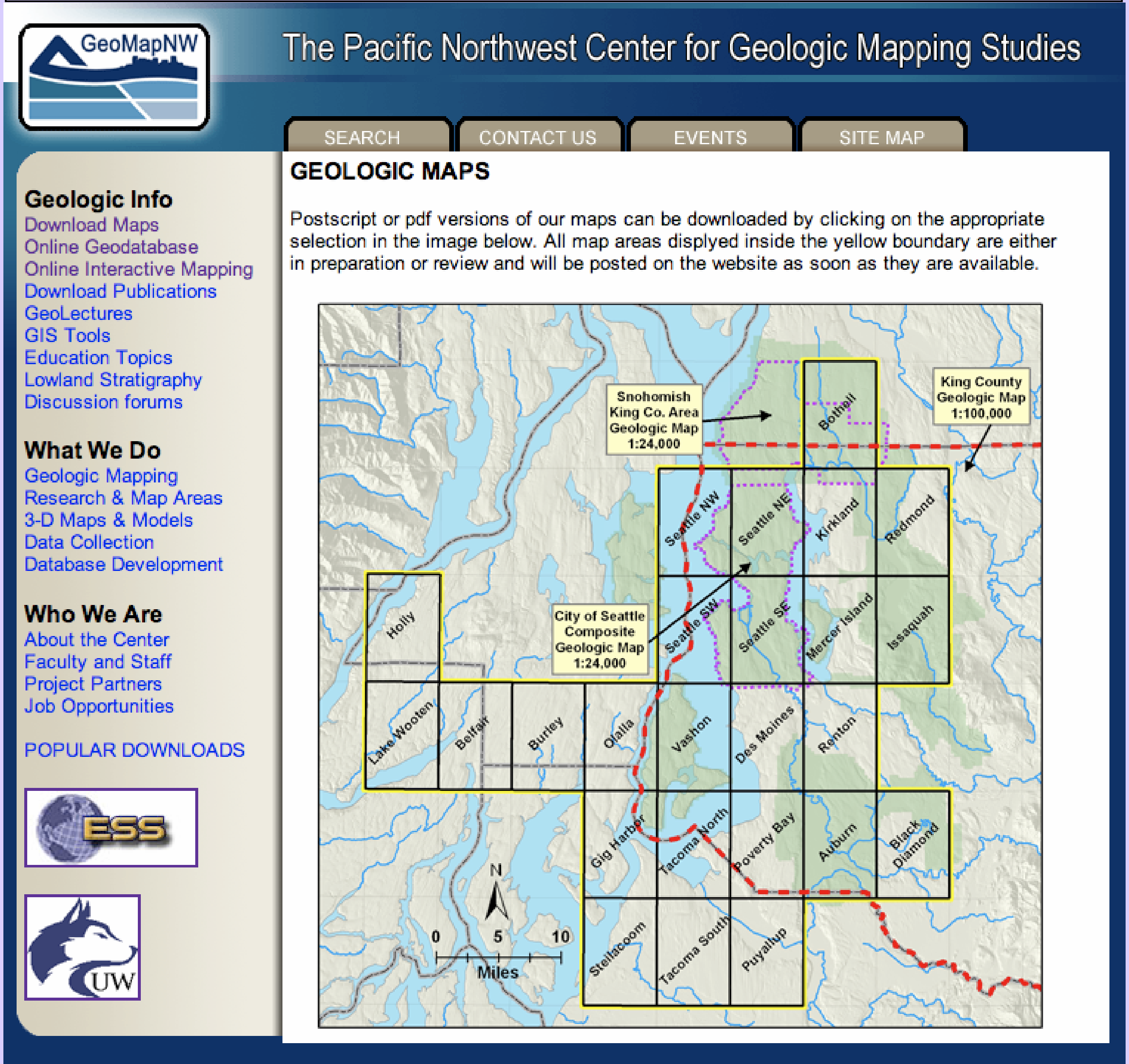
We map the local geology



using subsurface logs and surface observations.

High-resolution surficial/shallow geologic data; the GeoMap Project

http://geomapnw.ess.washington.edu



GeoMapNW

The Pacific Northwest Center for Geologic Mapping Studies

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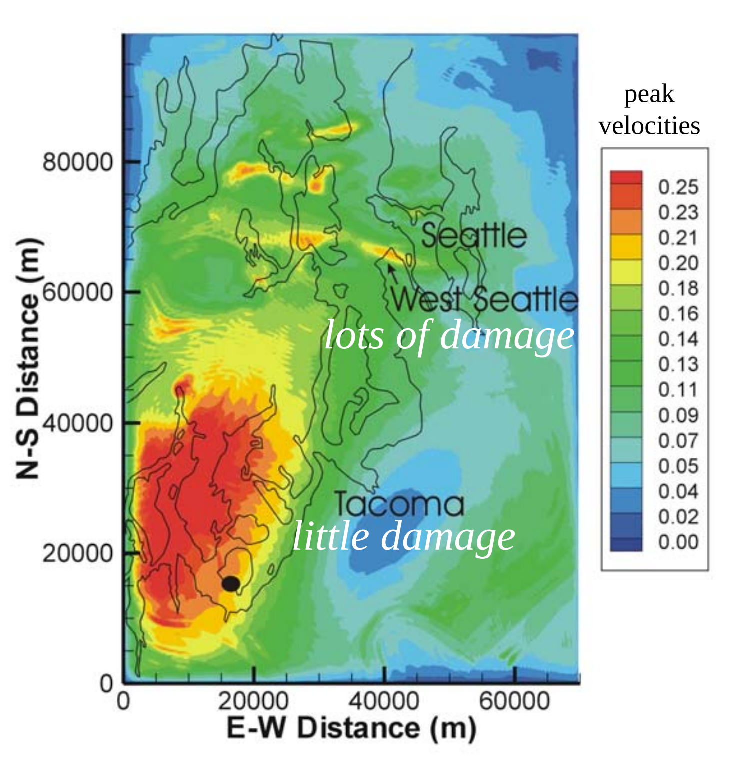
Postscript or pdf versions of our maps can be downloaded by clicking on the appropriate selection in the image below. All map areas displyed inside the yellow boundary are either in preparation or review and will be posted on the website as soon as they are available.

3D Simulation of the 2001 Nisqually Earthquake Shaking



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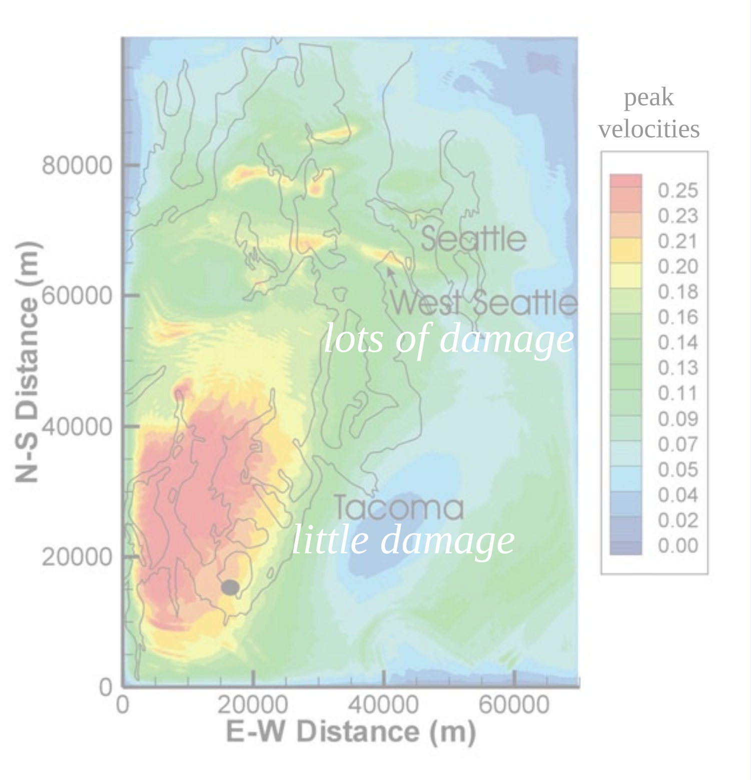
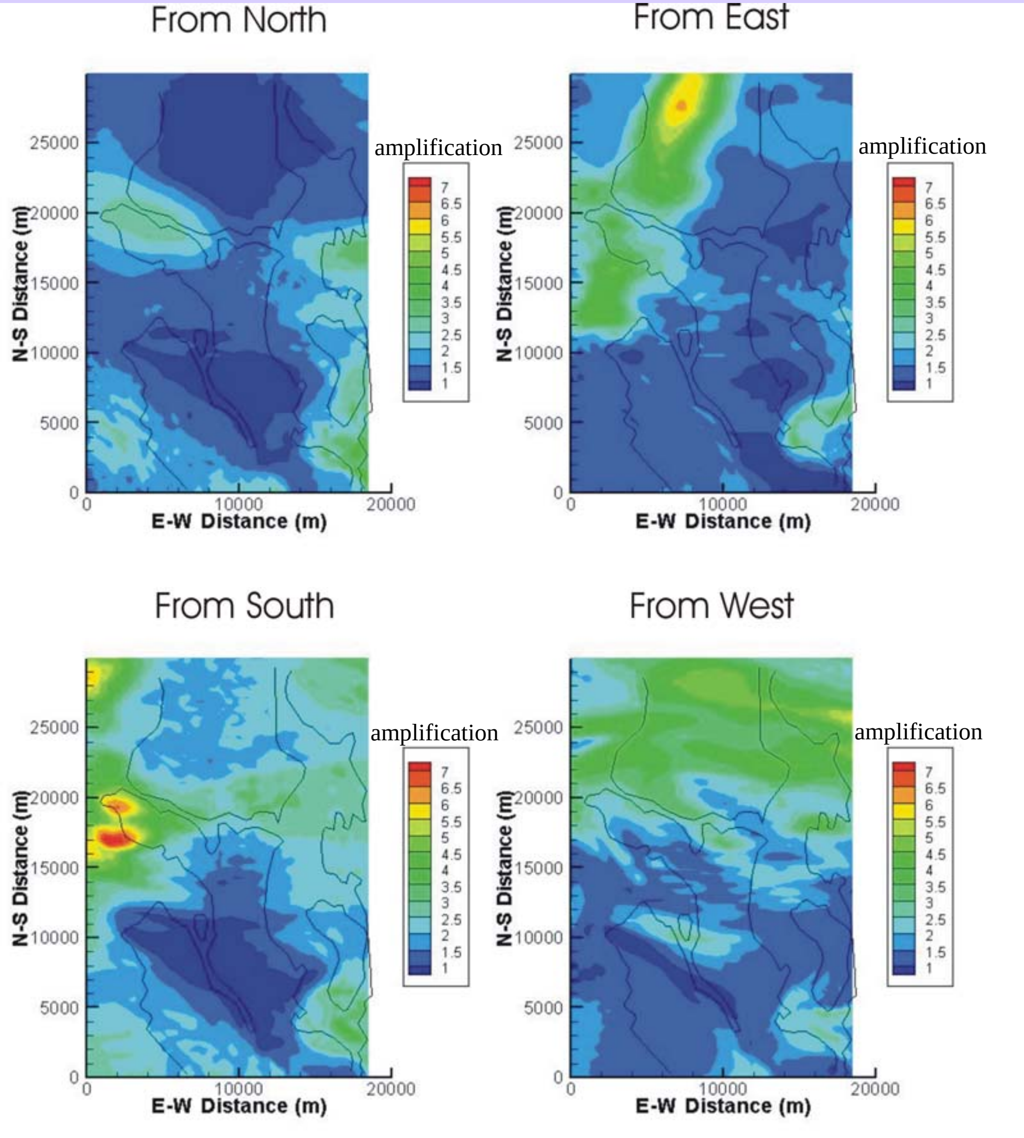
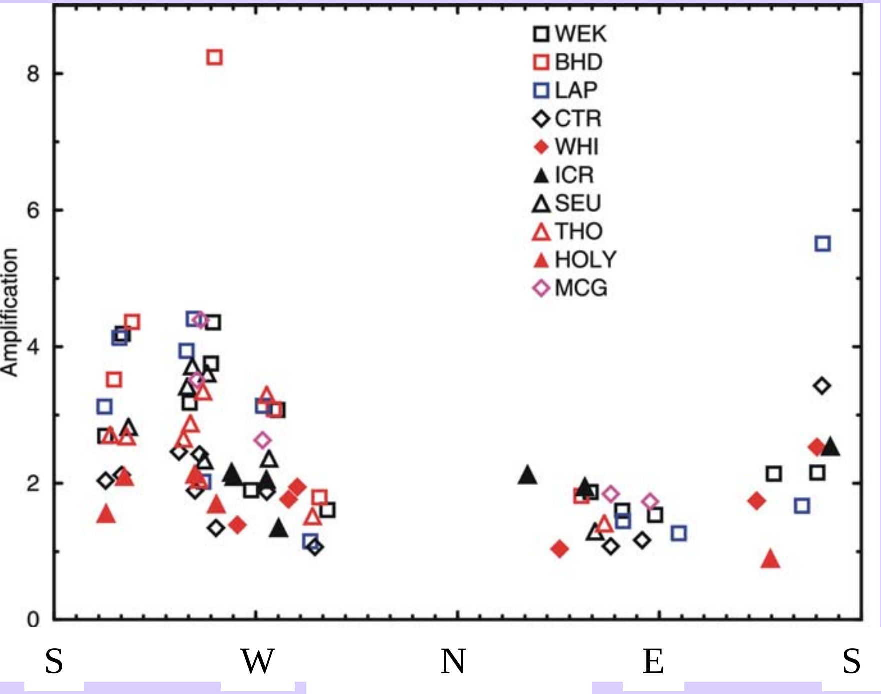


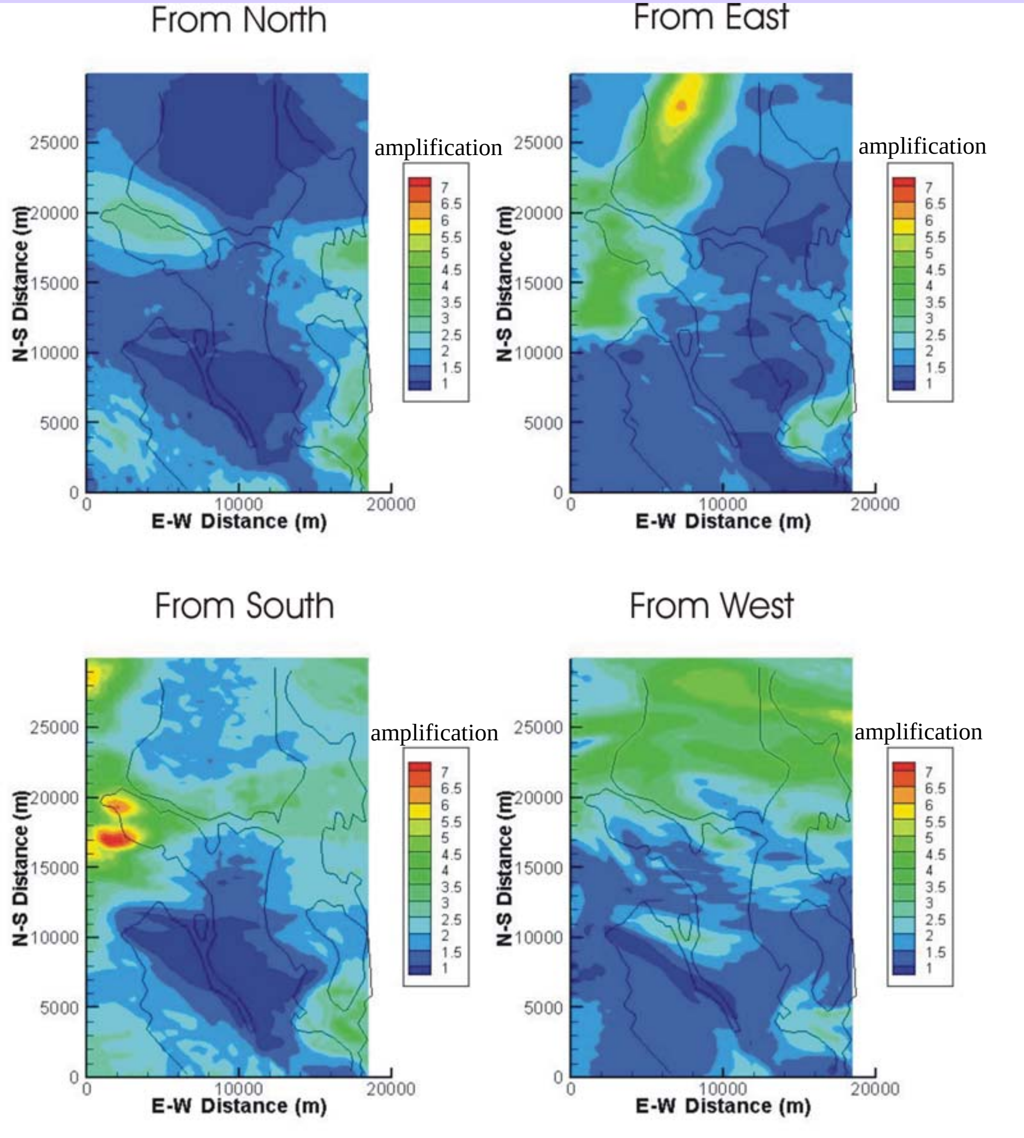
Lots of Simulations -> Earthquakes south of Seattle amplify more!



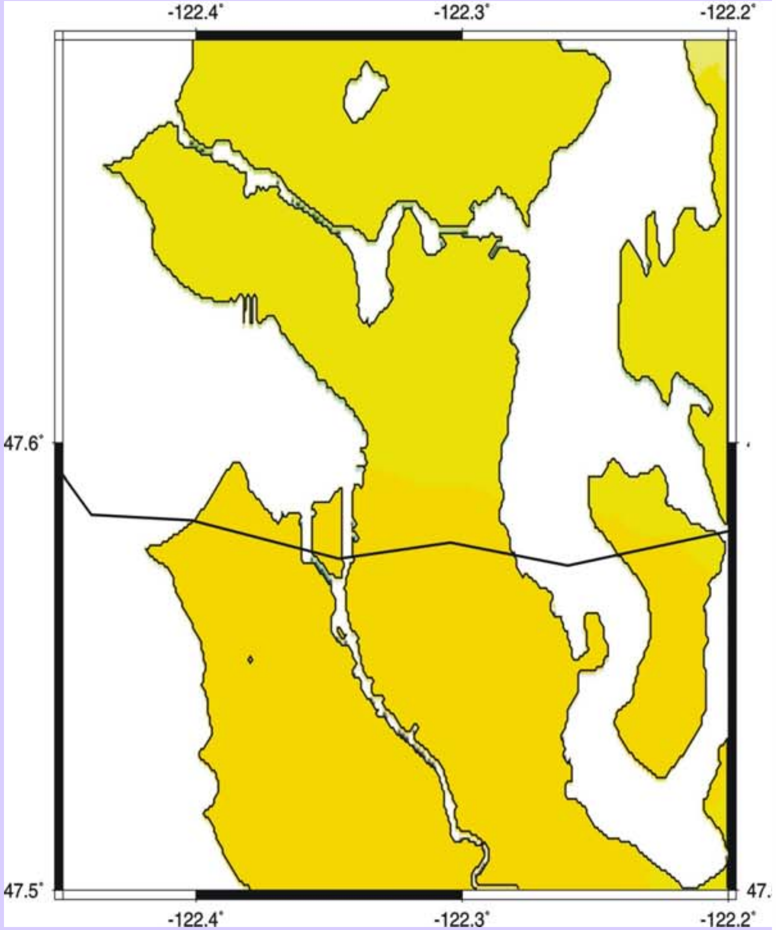
We ‘ground truth’ these with real measurements.

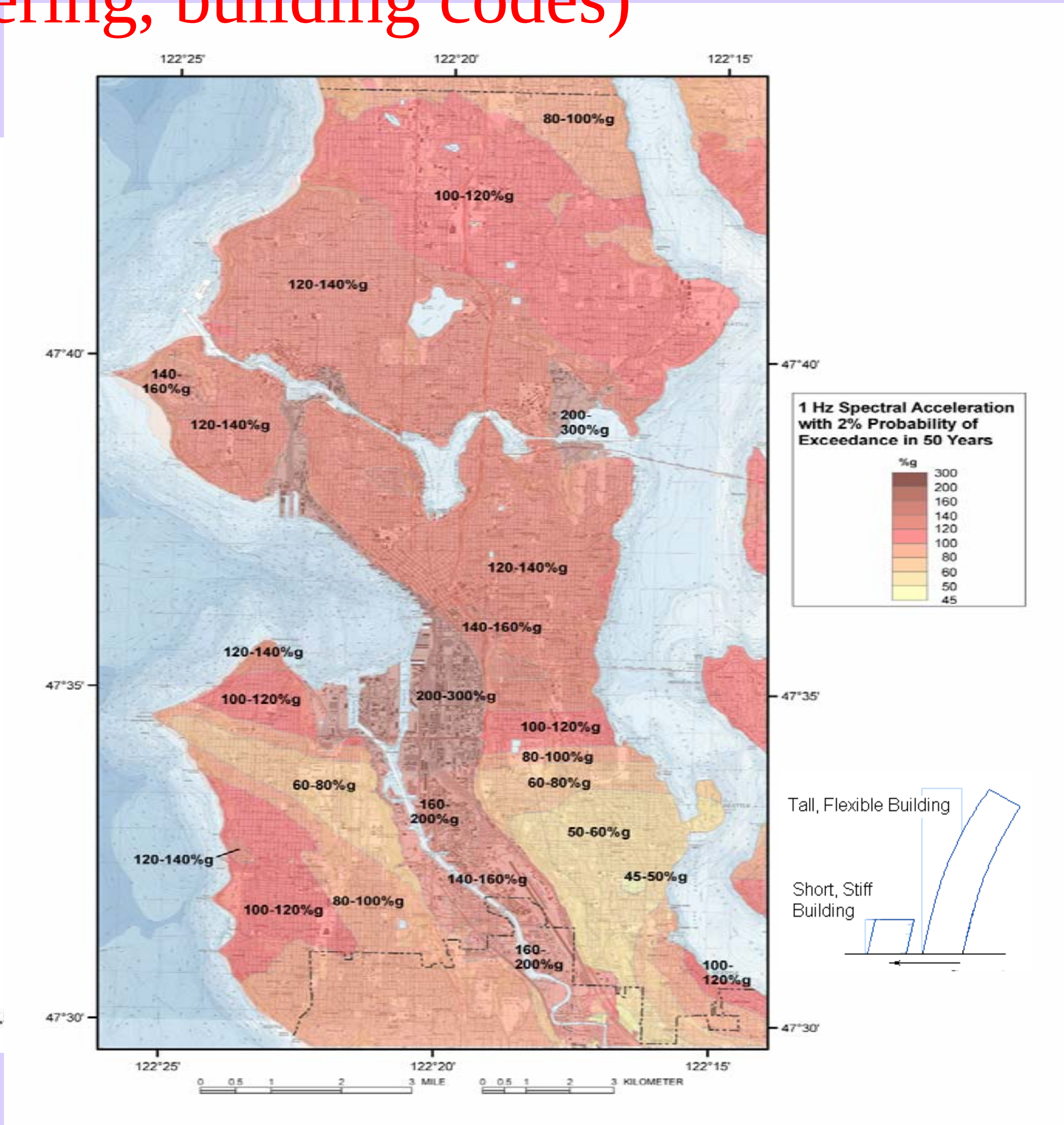
Lots of Simulations -> Earthquakes south of Seattle amplify more!





Combine everything in probabilistic maps (*e.g.* for engineering, building codes)





National Map - No Local Info

(2% in 50 Year Probability of Exceedance)

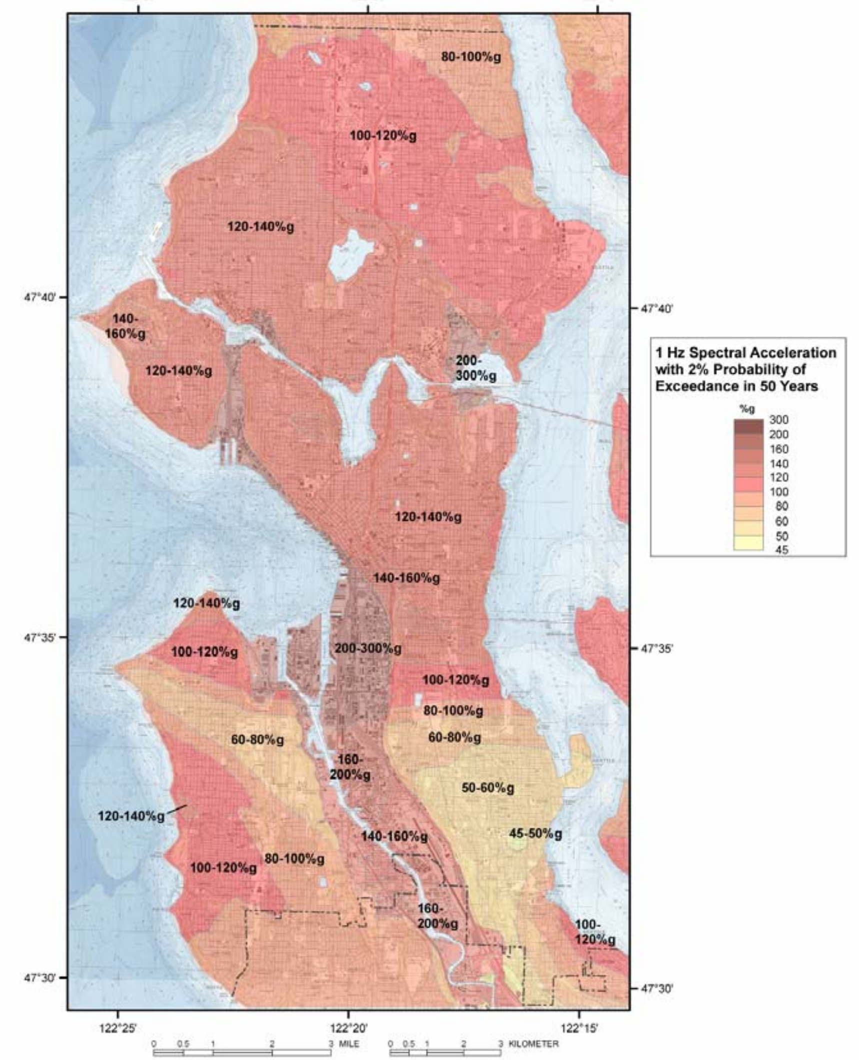
Urban Map - With Local Info

(2% in 50 Year Probability of Exceedance)

Multiple Maps for Different Risk (Probability) Levels

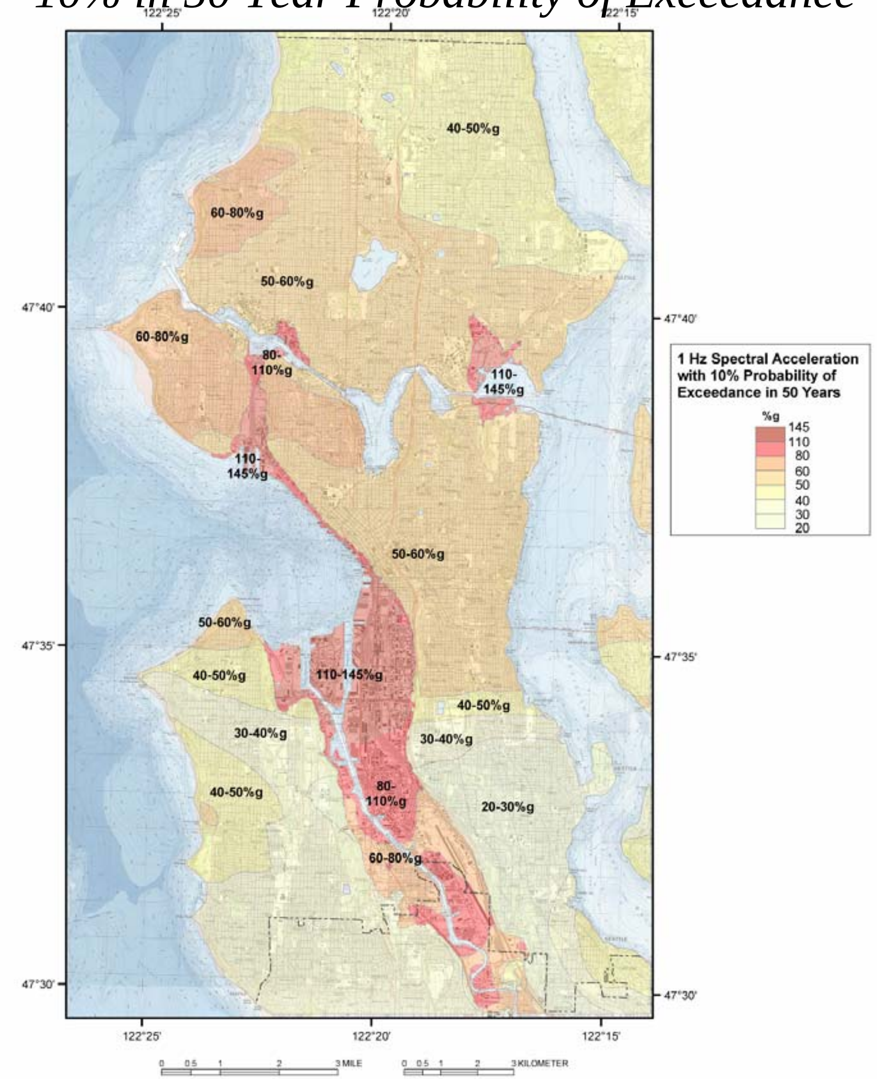
Less likely,but more extreme shaking
(e.g., for critical structures)

2% in 50 Year Probability of Exceedance



More likely, smaller shaking
(e.g., for ‘basic’ structures)

10% in 50 Year Probability of Exceedance



http://earthquake.usgs.gov/regional/pacnw/hazmap/seattle